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TECHNICAL REPORT GL-79-2

TRAFFIC TESTS OF EXPEDIENT AIRFIELD CONSTRUCTION CONCEPTS FOR POSSIBLE APPLICATION IN THE NATIONAL PETROLEUM RESERVE ALASKA (NPRA)

by

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March 1979

Final Report

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Report GL-79-2

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
9

4. TITLE (and Subtitle)
6
TRAFFIC TESTS OF EXPEDIENT AIRFIELD CONSTRUCTION CONCEPTS FOR POSSIBLE APPLICATION IN THE NATIONAL PETROLEUM RESERVE ALASKA (NPRA).

5. TYPE OF REPORT & PERIOD COVERED
Final report.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10
Cecil Burns
Dawson

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Geotechnical Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
12 138p.

11. CONTROLLING OFFICE NAME AND ADDRESS
Department of the Interior
U. S. Geological Survey
Menlo Park, Calif. 94025

12. REPORT DATE
11
Marc[redacted]79

13. NUMBER OF PAGES
123

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
14 WES-TR-GL-79-2

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Airfield construction
Construction in permafrost
Expedient construction
Expedient surfacings
Insulation
Landing mats
National Petroleum Reserve Alaska
Runways
Traffic tests

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study was conducted to evaluate several different concepts of runway construction for possible application at the National Petroleum Reserve Alaska (NPRA) drilling sites. The runways are to be constructed during the winter months on permafrost and be capable of supporting C-130 aircraft for a period of at least 2 years. Five separate test sections were constructed and traffic tested with a test load cart simulating a C-130 aircraft loading. Construction concepts included in the study were:

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DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

038 100 Gw 79 06 04 113

20. ABSTRACT (Continued)

a. Prefabricated aluminum landing mat over Styrofoam insulation;

b. Gravel base course over Styrofoam insulation;

c. Gravel base over loosely placed saturated sand fill; and

d. Sand-grid confinement fills.

The significant finding from this study was that a landing mat or a good-quality, well-compacted gravel base, at least 15 in. thick, placed directly over a sufficient thickness of 60-psi Styrofoam insulation material to prevent thaw in the frozen subgrade will provide a satisfactory runway for C-130 aircraft operations.

PREFACE

The investigation reported herein was sponsored by the Department of the Interior, U. S. Geological Survey, Menlo Park, California. The study was conducted by personnel of the Geotechnical Laboratory, U. S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively. Personnel actively engaged in the planning and conducting of the investigation were Messrs. R. L. Hutchinson, A. H. Joseph, C. D. Burns, C. L. Rone, A. L. Sullivan III, and S. J. Alford and Dr. W. R. Barker. The analytical analysis on minimum gravel thickness requirements in Part V of this report was made by Dr. Barker. This report was prepared by Mr. Burns.

Director of the WES during the conduct of the investigation was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurements used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
inches	25.4	millimetres
kips (1000 lb, mass)	453.5924	kilograms
mils	0.0254	millimetres
ounces (mass) per square yard	0.03390575	kilograms per square metre
pounds (force) per square inch	0.6894757	newtons per square centimetre
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.018489	kilograms per cubic metre
square feet	0.092903	square metres
square inches	6.4516	square centimetres
tons (2000 lb, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

TRAFFIC TESTS OF EXPEDIENT AIRFIELD CONSTRUCTION CONCEPTS FOR POSSIBLE APPLICATION IN THE NATIONAL PETROLEUM RESERVE ALASKA (NPRA)

PART I: INTRODUCTION

Background

1. The U. S. Geological Survey, Department of the Interior, has a problem of constructing several runways at exploratory drilling sites on the National Petroleum Reserve Alaska (NPRA). These runways are to be capable of supporting C-130 aircraft for a period of at least 2 years. Construction will be accomplished in the winter months on permafrost material. Gravel fills about 5 ft* thick are required to protect the permafrost during the summer for about a 2-month period, when the ambient temperature gets above freezing. The quantity of satisfactory gravel for these fills is difficult to obtain and is very costly to mine and transport to the drilling sites. Fine sand is readily available at the drilling sites, and consideration is being given to constructing fills using from 3 to 4 ft of sand with about a 2-ft gravel base. The main problem with the sand in the borrow areas, which can be used for fill, is that the moisture content is quite high, generally 15 to 20 percent by dry weight, and there are some indications that drainage characteristics may be poor. Therefore, if fills are constructed with mined frozen sand, a relatively low density is anticipated that will result in considerable settlements during the thaw season and, if the sand does not drain, will cause a loss of stability. The U. S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, is assisting the U. S. Geological Survey, Department of the Interior, in site selection, laboratory tests, and other theoretical studies for

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

the design and construction of the airfields at the Inigok and Tunalik sites in the NPRA. Husky Oil Company is the prime contractor.

Objectives

2. The objectives of the study reported herein were to evaluate several different concepts of runway construction for possible application at the NPRA drilling sites. Specifically, it was desired to evaluate concepts for construction at the Inigok and Tunalik sites where construction was to be accomplished during the winter of 1977-78.

Scope

3. Five separate test sections were constructed, and traffic tested with a test load cart simulating a C-130 aircraft loading. Construction concepts included in the test sections were:

- a. Prefabricated aluminum landing mat over Styrofoam insulation over high-strength subgrade representing permafrost material.
- b. Gravel base course over Styrofoam insulation over high-strength subgrade representing frozen permafrost material.
- c. Gravel base over loosely placed saturated sand fill.
- d. Sand-grid confinement in loosely placed saturated sand fill.
- e. Sand-grid confinement in highly compacted sand fill.

Approach

General

4. The approach was to construct small-scale runway test sections for each of the construction concepts being considered and to evaluate the construction based on performance under simulated C-130 aircraft traffic. Efforts were made to select materials for the construction to simulate as closely as possible the materials that could, or would be, available for construction at the NPRA drilling sites and to use

construction techniques to simulate the prototype runways to be constructed on and with frozen materials.

Definition of terms

5. The pertinent terms used in this report are defined as follows:

a. Pass. One trip of a load cart, or piece of compaction equipment, as it traverses a test item from one end to the other in either direction and to one takeoff and landing of an aircraft on a runway.

b. Coverages. The number of times a given area of a test item or lane is subjected to loading by the contact width of a tire load passing over the surface.

c. Traffic distribution. The manner in which traffic is distributed laterally with a test load cart on the test section and with aircraft operations on runways and taxiways.

d. Pass-coverage ratio. The equivalent number of passes of an aircraft on a runway as related to coverages of a load wheel on a test section. This factor varies for different aircraft and is dependent upon the aircraft gear configuration and the normal lateral distribution of the aircraft wheels on repeated takeoffs and landings. For the C-130 aircraft, one coverage on a test section is equivalent to 4.05 passes or takeoff and landing operations on a runway.

e. California Bearing Ratio (CBR). A measure of the resistance of soils to penetration, which is determined by comparing the bearing value obtained from a penetration-type shear test with a standard bearing value obtained on crushed rock. The standard results are taken as 100 percent, and values obtained from other tests are expressed as a percentage of the standard. CBR may be modified by the terms laboratory, field in place, and soaked or unsoaked, according to the conditions under which the specimens are prepared for tests or where the tests are made.

f. Airfield index. The average of a number of penetrometer readings in a given plane. The airfield penetrometer consists of a 30-deg cone with a base diameter of 0.5 in. (area = 0.196 sq in.) mounted on a graduated staff on top of which are a tension spring and handle. The force required to move the cone slowly through a given plane is an index of the shearing resistance of the soil. The penetrometer readings have been correlated with CBR, and airfield index numbers are roughly equal to CBR.

Materials

6. Sand. CRREL has been conducting laboratory tests on samples of sand and gravel material obtained from selected borrow areas in the

vicinity of the proposed runway sites. It was desired that the test sections at the U. S. Army Engineer Waterways Experiment Station (WES) be constructed with materials having properties as near as possible to that which is available for construction at the proposed drilling sites. Curve 2 in Plate 1 is a gradation curve, furnished by CRREL, which represents the sand available in an approved borrow area at the Inigok drilling site. Curve 1 in Plate 1 shows the gradation of a sand obtained locally near Vicksburg and used in WES Test Sections Nos. 2, 3, and 5; and, as can be noted, the gradation is very close to that of the Inigok borrow sand. Laboratory compaction data for the sand are shown in Plate 2a, and a plot showing the relationship of permeability versus void ratio is shown in Plate 3.

7. Gravel. The gravel used as base course in Test Sections Nos. 1 and 2 and as subbase in Test Section No. 4 was obtained locally and is a pit-run, gravelly sand (Curve 3, Plate 1). Curve 4 in Plate 1 shows the gradation of Colville River gravel, furnished by CRREL, which is a possible source of gravel for the Inigok air strip. The Colville gravel is probably too coarse and open graded to obtain the necessary stability to support C-130 aircraft; and, if this gravel source is used for a runway base course, the oversized gravel will probably be crushed, and some sand will be blended with the material to improve its gradation. Laboratory compaction data for the gravelly sand used in the test sections is shown in Plate 2b. The laboratory Corps of Engineers (CE) 55 blow compaction effort* resulted in an optimum water content of 7.4 percent and maximum density of 131.4 pcf.

8. Insulation. The insulation material used in Test Sections Nos. 1 and 3 was 24- by 48- by 1-1/2-in. panels of Styrofoam HI (60 psi). The material has a unit weight of 2.6 pcf and a compressive strength of 60 psi. The insulation material used in Test Section No. 4 was 24- by 96- by 2-in. panels of Styrofoam HI (60 psi). The Styrofoam insulation

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* American Society for Testing and Materials, "Standard Methods of Test for Moisture-Density Relations of Soils Using 10-lb Rammer and 18-in. Drop," Designation: D 1557-70, 1972 Annual Book of ASTM Standards, Part II, 1972, Philadelphia, Pa.

was obtained from Dow Chemical Company and is the same material as that being procured for the NPRA construction.

9. Landing mat. The landing mat used in the test sections is designated XM19, an all-bonded aluminum honeycomb mat. The mat was fabricated by Kaiser Aluminum Company in approximately 4-ft-square, 1-1/2-in.-thick panels. The actual mat used in the tests was obtained from Dyess Air Force Base, Texas, where it was service tested under both cargo- and fighter-type aircraft for several years starting in October 1966.

10. Filter fabric. The filter fabric used in Test Sections Nos. 2 and 3 was a spunbonded, needlepunched, polyester, nonwoven material called "Bidim." It has a unit weight of 12 oz per sq yd and was obtained from the Monsanto Textiles Company, St. Louis, Missouri.

11. Membrane. The waterproof membrane used in Test Section No. 2 was a 6-mil polyethylene material obtained from a local building supply company.

12. Paper grid. The paper grid used in Test Sections Nos. 3 and 5 was procured from the Hexcell Corporation, Los Angeles, California, and was made from linerboard with a unit weight of 90 lb per 1000 sq ft. The grid was made in a honeycomb figuration with cell sizes of 6 by 6 by 6 in., 8 by 8 by 6 in., and 12 by 12 by 6 in. When expanded, the panel size was 8 by 24 ft. The paper was treated with a phenolic resin, about 9 percent by weight, to improve the wet strength of the material.

Load carts

13. Two specially designed load carts were used in the application of traffic on the test sections. A single-wheel test cart (Figure 1) loaded to provide a single-wheel load of 35 kips was used to simulate the loading conditions of a C-130 aircraft for the traffic applied in Test Section No. 1 and the initial traffic in Test Section No. 2. For the final traffic in Test Section No. 2 and all simulated aircraft traffic in Test Sections Nos. 3, 4, and 5, a different load cart (Figure 2) was used. This latter cart was equipped with a single-tandem gear (one main gear of a C-130 aircraft) loaded to 70 kips. The load wheels of both carts were equipped with 20x20, 20-ply tires inflated to 100 psi.

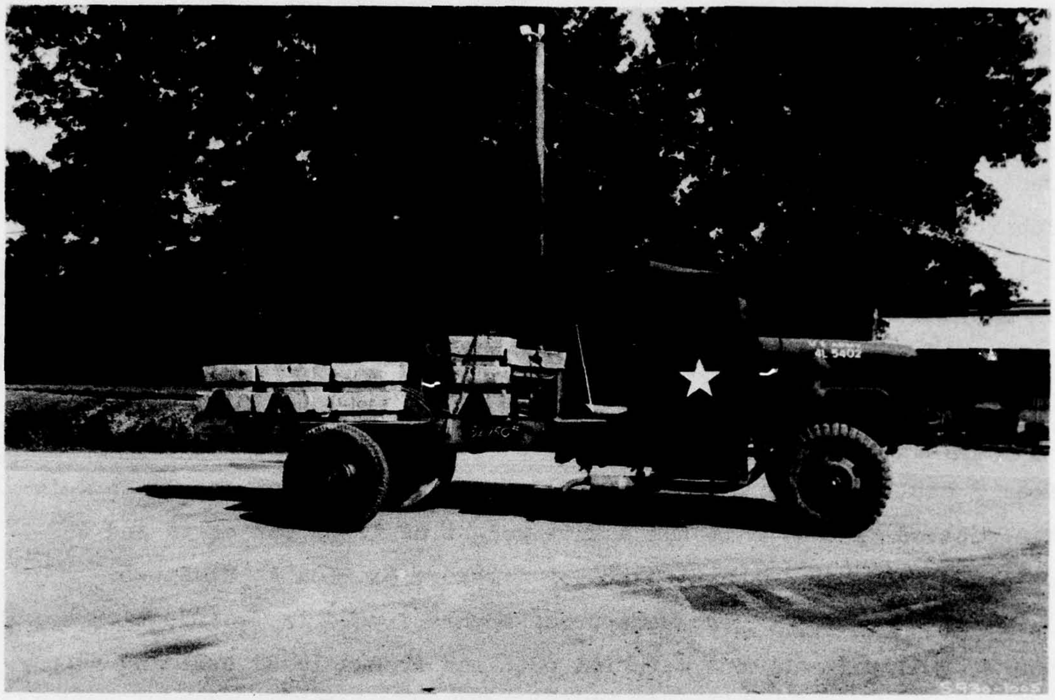

Figure 1. Thirty-five-kip single-wheel test cart

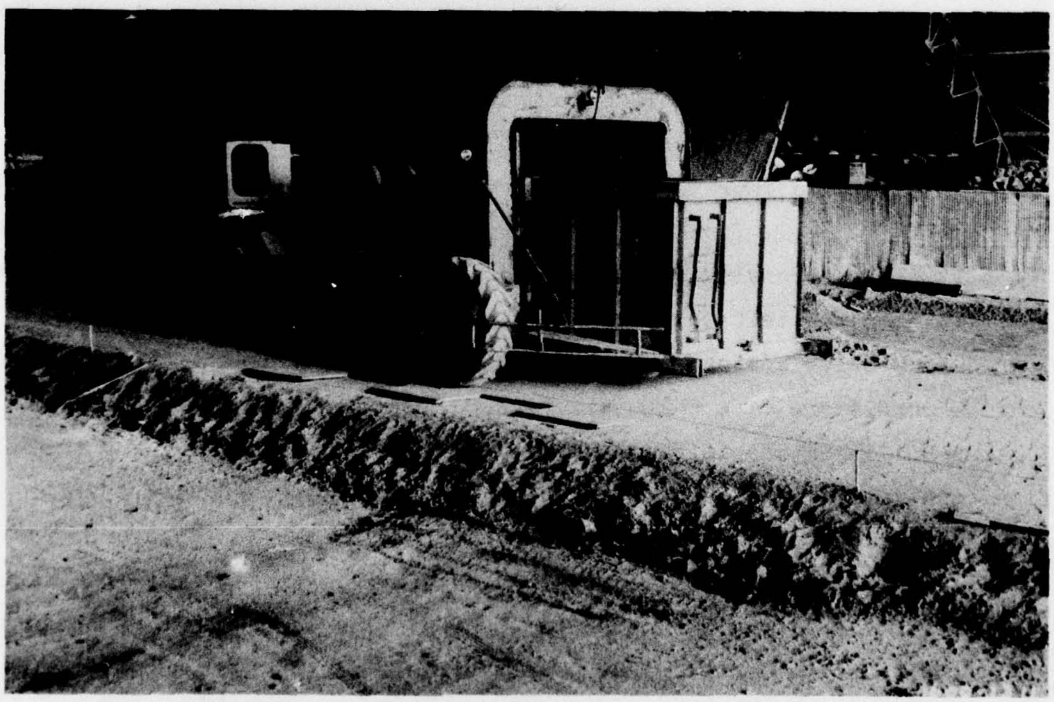

Figure 2. Seventy-kip single-tandem test cart

Traffic patterns

14. The single-wheel load cart traffic was distributed in a traffic lane 10 ft wide to simulate the distribution normally encountered in actual aircraft takeoffs and landings. The trafficking sequence was to start at one side of the lane, drive forward, and then backward in the same path for the length of the traffic lane. The path of the cart was then shifted laterally approximately 15 in. (the width of tire print) on each successive forward trip. The full width of the traffic lane (120 in.) was trafficked in this manner, resulting in all points being subjected to two coverages of a loaded tire. The interior 90 in. of the the traffic lane was then trafficked for six additional coverages. The center 60 in. of the traffic lane then received two additional coverages. This traffic pattern shown in Plate 4 required a total of 60 passes of the load cart and resulted in a maximum of 10 coverages of the load wheel over the center 60 in. of the traffic lane. This pattern of traffic application was repeated until traffic was discontinued. The traffic distribution curve shown in Plate 4 is typical of the normal distribution of actual takeoffs and landings of aircraft on a runway. Based on traffic distribution studies of aircraft on runways, the pass-coverage ratio for the C-130 aircraft is 4.05. Thus, one coverage of traffic on the test section is equivalent to 4.05 takeoffs and landings on a runway.

15. The width of the test sections was not wide enough to permit the normal traffic distribution pattern with the single-tandem load cart. Thus, the traffic lanes were narrowed to either three-tire- or five-tire-print widths, and the traffic was applied uniformly over the center three-tire-print width (45 in.). The coverages applied in this manner would represent the traffic that would be applied at the peak of the normal distribution curve.

PART II: TEST SECTION NO. 1, LANDING MAT AND GRAVEL OVER INSULATION

Objective

16. The objective of this test section was to evaluate the performance of runway construction using Styrofoam insulation over permafrost material with prefabricated landing mat and gravel surfacing over the insulation.

Test Section

Description

17. A layout of Test Section No. 1 is shown in Plate 5. The test section was 80 ft long by 25 ft wide and consisted of two test items, each 40 ft long. The test section was constructed under shelter in a hangar test facility. The subgrade for both test items consisted of a lean clay soil well compacted to produce a relatively high-strength representative frozen material. The subgrade for each item was covered by two layers of 1-1/2-in.-thick Styrofoam insulation material, or a total thickness of 3 in. Test item 1 was surfaced with XM19 aluminum mat, and item 2 with 20 in. of pit-run, gravelly sand, base course material.

Construction

18. An area 80 ft long by 25 ft wide divided into two test items, each 40 ft, was laid out. The existing soil in the test area was excavated to about 8 in. below the desired subgrade elevation and backfilled with a lean clay soil. This material was processed to about optimum water content and compacted with a 25-ton, self-propelled, pneumatic-tired roller. After compaction, the subgrade was fine-graded to the desired subgrade elevation. The in-place density of the compacted subgrade was 102 pcf (approximately 90 percent of CE 55 maximum laboratory density) at an average water content of 16.2 percent. As a result, the in-place

CBR value was about 17, which is considered to be a medium-to-strong foundation and was used to simulate a frozen subgrade.

19. The subgrade in both items 1 and 2 was covered with two layers of the 1-1/2-in.-thick insulation material. The insulation panels were placed by hand in such a pattern that all joints in the bottom layer were overlapped by the top layer (Photos 1 and 2).

20. The surfacing used over the insulation in item 2 was 20 in. of the gravelly sand material described in paragraph 7. The gravel was hauled and dumped onto the Styrofoam material with end dump trucks and distributed with a front-end loader and a D-4 tractor. Care was used to prevent disturbance of the insulation panels. The gravel was placed at about optimum water content and compacted in three layers. The first layer had a compacted thickness of about 12 in., and the top two lifts about 5 in. each. Compaction was accomplished with a 25-ton, self-propelled, pneumatic-tired roller. The surface of the compacted base was graded with a motor patrol to provide a smooth surface with a uniform thickness of 20 in. over the Styrofoam insulation. The in-place density of the compacted base course was 138 pcf at a water content of 5.2 percent and an in-place CBR of about 40. Photo 3 shows a general view of the finished base course prior to traffic.

21. The XM19 landing mat was placed directly on the insulation material in test item 1 (Photo 4). Photo 5 presents a general view of the mat surface in item 1 prior to traffic.

Traffic testing

22. A total of 1250 passes of traffic with the 35-kip single-wheel load, which resulted in about 210 coverages in the center portion of traffic lane and represented about 850 C-130 operations, was applied to both test items. Photo 6 indicates little or no effect of this traffic on the landing mat surfaced item. The small amount of settlement of the base in test item 2 was due to some lateral displacement of the gravel and a slight increase in density of the base under traffic. Photo 7 shows a general view of item 2 after traffic. The typical cross sections in Plate 6 show the surface elevation of the two test items prior to traffic and at the end of 1250 passes. In-place water content, density,

and CBR determinations of the base course in item 2 at the end of traffic indicated an average dry density of 139 pcf, at a water content of 4.4 percent and in-place CBR of about 55.

23. At the end of the traffic, the mat was removed from item 1, and an excavation trench was made in item 2 to permit examination of the Styrofoam insulation material. It was determined that the insulation panels were still in place with no damage in either item. Photo 8 shows a general view of the insulation in test item 1, after traffic and removal of mat. As indicated in Photo 9, some slight grooving and ridges were formed in the insulation material by the joints and weld seams in the XM19 mat and a few cracks in the insulation material. However, it is believed that this would have no adverse effects on the insulation properties of the Styrofoam panels.

24. Since there was no damage to the insulation under the 20-in. gravel base in item 2, it was decided to remove the top 10 in. and apply additional traffic to determine if a lesser thickness of gravel would adequately protect the Styrofoam insulation. About 240 passes of the 35-kip single-wheel load were applied over item 2 after the removal of the top 10 in. of base. This resulted in considerable rutting of the base course, and at 240 passes the load cart became immobilized in about a 3-in. rut (Photo 10). An excavation trench made at this time revealed that the Styrofoam insulation panels were being compressed under the load wheel and the thickness of the Styrofoam boards had decreased from 1-1/2 to about 1-1/4 in. Therefore, it was concluded that a 10-in. gravel base was not adequate to protect the insulation, and traffic was discontinued.

Conclusions

25. Based upon the results of tests reported herein, the following conclusions are warranted:

- a. XM19 aluminum landing mat placed over a sufficient thickness of 60-psi Styrofoam insulation to prevent thaw in the frozen subgrade will provide a satisfactory runway for C-130 aircraft traffic.

b. A 20-in.-thick, good quality gravel base course constructed over 60-psi Styrofoam insulation material will protect the Styrofoam from compression under the C-130 aircraft loading but will probably require some maintenance during aircraft operations.

PART III: TEST SECTION NO. 2, GRAVEL OVER SATURATED SAND

Objective

26. The objective of this study was to determine if a fill constructed of frozen sand and surfaced with 20 in. of gravel base course would sustain C-130 aircraft traffic after the sand below the gravel thaws. The test section described herein was designed and constructed to try to simulate the degree of compaction and quality of construction that would be obtained in Alaska using frozen sand and gravel material.

Test Section

Description

27. A layout of Test Section No. 2 is shown in Plate 7. This section was 140 ft long by 25 ft wide and consisted of three test items, each 40 ft long with a 10-ft transition between adjacent items. Item 1 consisted of 20 in. of gravel over 6 in. of saturated sand; item 2 consisted of 20 in. of gravel over 36 in. of saturated sand. Item 3 was the same as item 2 except that filter cloth fabric was used to line the walls of the excavation and placed horizontally at 1-ft intervals in the sand fill (Plate 2). The filter fabric was used in this item to determine if it would result in improved drainage and an increase in the load-carrying capacity of the sand.

Construction

28. A test trench 25 ft wide by 140 ft long was excavated under hangar No. 4 at the WES (see layout, Plate 7). The depth of excavation was approximately 15 in. for test item 1 and 45 in. for test items 2 and 3. The foundation soil at the bottom of the excavation was a lean clay material, which was compacted and graded to zero slope at the desired elevation. As indicated in Plate 7, a 10-ft-wide transition area was constructed between the various test items with lean clay soil. A trench approximately 1 ft wide and 6 in. deep was excavated along the west side

of each test item where a 4-in.-diam perforated pipe was to be installed for later use in the saturation of the sand fills. The bottom and sides of the test trenches and the transition areas were lined with waterproof polyethylene membrane, as shown in Photo 11, to protect the clay soil from the intrusion of water. The perforated pipe was then wrapped with a filter cloth and installed in a trench along the west side of test items (Photo 11). A 9-in.-thick blanket of washed gravel was then placed over the membrane. The 4-in. perforated pipe was installed in the gravel along the west side. A lateral trench was excavated to the west side of each test item connecting the test items to a sump. A solid 4-in.-diam polyvinyl chloride (PVC) pipe connecting to the perforated pipe in the test section was installed with a slight slope to sump (section B-B, Plate 7). This pipe was capped off at the sump. An open, vertical standpipe was installed for supplying water to the sand through the perforated pipe and gravel blanket after construction of the test section. An additional standpipe was placed in the water line and capped off at the surface elevation of the washed gravel. Photo 12 shows a general view of the finished gravel blanket. The gravel blanket was covered with a filter cloth to prevent the sand from filtering into the gravel layer. The sand was end dumped onto the filter fabric from dump trucks along the sides and ends of test items (Photo 13). The material was then spread to the desired elevation with a D-4 tractor. A front-end loader and hand labor were also used in spreading and leveling the sand.

29. During placement of the sand, piezometer tubes were placed in the sand at the locations shown in Plate 7. In item 3, the filter cloth, which was placed over the washed gravel in each test item, was extended up the sides and end of the excavation trench (Photo 14). The sand was placed in 1-ft layers with a layer of filter cloth placed between each layer of sand and at the top of the 3-ft sand fill.

30. The gravel base was dumped onto the sand and spread over the entire test section with a D-4 tractor in two 10-in.-thick compacted lifts. Compaction was accomplished by a 25-ton, self-propelled, pneumatic-tired roller with 90-psi tire pressure. The surface of the

base was graded with a motor grader, and final rolling was accomplished with a light-weight, smooth wheel vibratory roller. Photo 15 shows a general view of the finished test section.

31. The as-constructed average dry density of the base course was 126.5 pcf at an average water content of 5 percent. This is about 96 percent of the laboratory maximum density as obtained with the CE 55 blow compaction effort.

32. Test pits were excavated through the base course to the top of the sand layer, and the as-constructed density and water content of the sand were measured. These tests indicated an average in-place dry density of 102.0 pcf at a water content of 7.2 percent, which is about 87 percent of the laboratory maximum density.

Traffic testing

33. Prior to the application of traffic, water was induced into the sand through the open standpipes until the piezometers, which were installed in the various items during construction, indicated that the sand was fully saturated. The sand was saturated from the bottom up through the gravel layer in the bottom of test items.

34. The initial traffic was applied in a 10-ft-wide traffic lane with the 35-kip single-wheel load. On the first pass of the load cart, rather large deflections were observed in all test items, and water was being forced out of the sand through the standpipes, which were used for inducing the water. With repetitive passes of the load cart, the water would continue to drain and rise in the piezometer tubes to a level several inches above the surface of sand elevation. Due to the heavy load and high deflection of the base, it was difficult to get adequate traction of the front-wheel drive power unit towing the load cart, and the drive wheels were causing considerable disturbance to the surface of the base course. This was particularly true in test item 1 where the cart was being shifted laterally on each forward pass. The lean clay transition areas between items 1 and 2 and items 2 and 3 apparently got wet during the saturation of the sand and deteriorated rapidly under traffic. By the end of 12 passes, which represent about eight takeoffs

and landings of a C-130 aircraft, it was necessary to overlay the transition areas with landing mat. Also at this time, shallow ruts about 1 in. deep had developed in the base course of all three test items, and in some areas, the drive wheels of the load cart had loosened and disturbed the base to a depth of 2 to 3 in. Therefore, before traffic was resumed, the surface of the base was smoothed up in all three test items.

35. As traffic continued, the deflection of the base increased under the load, and water was continuously forced out of the sand through the standpipes. After 22 passes (approximately 15 C-130 operations), it was very difficult to tow the load cart back and forth over the traffic lane with the front-wheel drive power unit being used, and the cart became immobilized in about a 2-in.-deep rut in item 2 on the last pass (Photo 16). Average rut depths at this time were about 0.5, 1.3, and 1.0 in., respectively, in items 1, 2, and 3. At this time, it was evident that 20 in. of gravel over 36 in. of saturated loose sand would not provide a stable runway for C-130 aircraft. However, the performance in item 1 was somewhat better, and traffic was continued for a total of 714 passes of the single-wheel test cart, which is equivalent to about 482 C-130 aircraft operations. Water continued to drain from this item throughout this period of traffic, and the stability appeared to improve with traffic. However, it was necessary to smooth up the surface of the base after about every 30 to 40 passes of the load cart. The base disturbance was caused more by the traction wheels of the load cart than by the main gear load wheel. Photo 17 shows a general view of item 1 at the end of 714 passes.

36. At the end of this initial traffic, the standpipes through which the water was induced into the sand were cut off 6 in. below the surface elevation of sand to permit the water to drain to this level, and traffic continued with a different load cart (Figure 2) equipped with a 70-kip single-tandem gear assembly representing one main gear of a C-130 aircraft. The gravel base course over all three test items was graded and recompacted prior to this traffic.

37. A total of 300 passes of traffic with the 70-kip single-tandem cart was applied to all three test items. This traffic was concentrated

in the center 4 ft of the traffic lane and was equivalent to about 810 C-130 aircraft operations. Water continued to drain throughout this period of traffic, and deformation of the surface developed in each item as the sand consolidated. Photos 18, 19, and 20, respectively, show a general view of test items 1, 2, and 3 at the end of traffic. The maximum total deformation at the center of the traffic lane at the end of the test was 1.0, 3.6, and 2.8 in., respectively, for test items 1, 2, and 3. The cross sections in Plate 8 show the original elevation of gravel surface prior to traffic with the 70-kip single-tandem gear load and after 20 and 300 passes. During the initial phase of traffic, the elastic deflection under load was quite high in all test items. However, as traffic progressed, considerable drainage and consolidation of the sand occurred and the stability improved. No maintenance of the base was required during this period of traffic. At the end of the traffic period, the water table in the sand was at the bottom of the 6-in. sand layer in item 1 and from 12 to 18 in. below the surface in test items 2 and 3.

<u>After-traffic testing</u>

38. At the conclusion of traffic, the free water was drained from the bottom of the sand layer, and test trenches were excavated across the traffic lane in each test item. Observations made in the test trenches showed the contour of the surface of sand to be about the same as the contour of the surface of base. Thus, it is indicated that most of the deformation occurred in the sand layer. Water content and density determinations were made in the base course layer and at the surface of the sand layer in item 1, and at the surface 12 and 24 in. into the sand in items 2 and 3, respectively.

39. Table 1 summarizes the water content and density data as determined in the base course after traffic. Table 2 presents the traffic test data, water content, and density determinations made in the sand after traffic.

Conclusions

40. The results from this test indicate that 20 in. of gravel over a frozen sand fill without insulation would be marginal at best for C-130 aircraft operations, after the sand thaws, depending upon how well the sand drains. With the sand fully saturated, an unstable condition may exist. However, if the sand drains and consolidates as it thaws, stability could be maintained by surface compaction and maintenance.

PART IV: TEST SECTION NO. 3, SAND-GRID CONFINEMENT LOOSE SATURATED FILL

Objective

41. The objective of this test section was to evaluate the effectiveness of a paper-grid material, placed in the upper portion of sand fills, in improving the stability and load-carrying capacity of the sand. Specific objectives were to determine the effects of the following variables:

- a. Depth of grid in sand.
- b. Effect of differential settlement.
- c. Performance of grid over insulation.

Description of Test Section

42. A layout of Test Section No. 3 is shown in Plate 9. The test section was constructed in a trench, 25 ft wide by 160 ft long, and consisted of five test items, each 30 ft long. The depth of sand in items 1 through 4 was 48 in., underlain by a 6-in. layer of washed gravel. In item 1, a single layer of the 6- by 6- by 6-in. grid was placed in the top 6 in. of the deep sand fill. In item 2, two layers of the grid were constructed in the top 12 in. of fill; and in item 3, three layers of grid were constructed to a depth of 18 in. into the sand fill. These items were designed to determine the depth of sand confinement needed to support a C-130 aircraft loading. Item 4, which consisted of two layers of sand-filled grid constructed over a variable strength subgrade, was designed to determine the performance of the sand-grid confinement system where differential settlement is likely to occur. Item 5 consisted of two layers of sand grid placed over insulation on a firm foundation to simulate a frozen material.

43. It was desired to place the sand in the fill at a low density to simulate the density that would be obtained during construction with

mined frozen sand in Alaska and to evaluate the load-carrying capacity of the grid-confined sand in a saturated state, which would represent a thawed condition in the Alaska environment. Therefore, the test section was designed and constructed to permit saturation of the sand from the bottom up after construction. Piezometers were installed in the section (Plate 9) for monitoring the free-water table in the sand before and during the application of traffic.

Construction

General

44. A test trench 25 ft wide by 160 ft long was excavated under hanger No. 4 at the WES (see layout, Plate 9). The depth of excavation was about 54 in. for test items 1 through 4 and about 15 in. for test item 5. The foundation soil at the bottom of the excavation was a lean clay material, which was leveled and compacted at the desired elevation. A trench approximately 1 ft wide and 6 in. deep was excavated at the bottom of the section along the west side of test items 1 through 4, where a 4-in.-diam perforated pipe was to be installed for later use in saturation of the sand fill. The bottom and sides of the test trench were then lined with a waterproof neoprene-coated nylon membrane. The perforated pipe was wrapped with a filter cloth and installed in the trench (Photo 21). A solid 4-in.-diam PVC pipe connecting to the perforated pipe was installed in a lateral trench with a slight slope to a sump (section B-B, Plate 9). The pipe was capped off at the sump. An open, vertical standpipe was installed for supplying water to the sand through the perforated pipe and gravel blanket after construction. A 6-in.-thick blanket of washed gravel was then placed over the waterproof membrane and around the perforated pipe in the bottom of the excavation (Photo 22). The washed gravel was then covered with a filter fabric (Photo 23).

Variable strength foundation

45. The variable strength foundation for test item 4 was constructed first. The high-strength material used for this item was a

pit-run sandy gravel, and the top 18 in. was stabilized with 6 percent portland cement. The gravel material was placed and then compacted in about 19-in.-thick compacted lifts over the entire 40-ft-long test item up to about 12 in. below final grade. After compaction of the stabilized base, two trenches 8 ft wide were excavated down to the surface of the filter fabric over the gravel blanket and the trenches were filled with loose uncompacted sand. Prior to placing the gravel, landing mats were placed over the filter fabric in the 8-ft-wide areas where the sandy gravel and mats would be later removed. The sandy gravel was then spread to the desired thickness and compacted with a pneumatic-tired roller. After construction of the high-strength base, the 8-ft-wide trenches were cut with a backhoe and the landing mat at the bottom of the trench was removed (Photo 24).

Placement of piezometers and sand

46. Piezometers were installed at the bottom of the sand fill in items 1, 2, 3, and 4 prior to placing the sand (Photo 25). The sand was then end dumped from the sides of the trench onto the filter cloth (Photo 26). The sand was rough graded to the desired elevation for installation of grids in each item, after which trenches were cut and additional piezometers were installed in the sand about 8 ft from the west side of the section and at 1-ft intervals of depths. One additional piezometer was placed at a depth of 2 ft below the sand grid in each item to measure water level during traffic. The sand was then leveled by hand to the desired elevation for placement of the grids (Photo 27).

Placement and filling of grids

47. The paper grids were received in pallets 32 in. wide, 16 in. deep, and 132 in. long (Photo 28). Each pallet contained 25 panels of grid. The individual grid panels were about 3 by 6 by 126 in. in the unexpanded condition (Photo 29). When expanded, each panel covered an area approximately 8 by 24 ft and 6 in. deep (Photo 30). In the initial placement of the grid, the panels were hand placed along one side of the test item and expanded across the test section for a 24-ft width by holding one side of the panel and pulling the other. After expanding, the grid was secured with steel pins pushed through the grid openings and

into the underlying sand. Sand was then dumped into the grid from each side with a front-end loader. The sand was distributed to the center of the section with hand shovels (Photo 31). In expanding the grid in the above manner, some tearing of the paper and glued joints was occurring (Photo 32). This problem was alleviated somewhat by placing the unexpanded grid panels in the center of the section and expanding them to both sides from the center.

48. A double layer of the 1-1/2-in. Styrofoam insulation material was placed over the waterproof membrane in item 5 (Photo 33). The first layer of paper grid was placed directly on the Styrofoam surface (Photo 34). In all test items where multiple layers of grid were used, there was about a 1-in. overbuild of sand between the grid layers. Photo 35 shows an end view of item 5 starting the top layer of the grid. Photo 36 presents an overall view of the finished test section.

49. For this test it was desired to place the sand in the grids in a loose state to simulate the density that would be obtained using mined frozen sand in Alaska. Therefore, no equipment was used on the grids in filling and leveling the sand. It was recognized that this would not be feasible for large-scale construction in the field and that equipment would have to replace much of the hand labor in filling the grids and leveling the sand over the top of the grid. Thus, to determine the effect of equipment working over the grid, two additional sections of the 6- by 6- by 6-in. paper grid 24 by 16 ft were placed in the maneuver area adjoining the north end of item 5. For this exercise, the sand was dumped onto the grid with a front-end loader, spread, and compacted with a D-4 tractor. The surface of the sand was maintained about 2 to 3 in. above the top of the grid. This resulted in a much higher density of sand in the grids and no apparent damage to the grid from the equipment operations.

Saturation of sand

50. Construction of the test section was completed on 25 January 1978. Saturation of the sand was initiated at 0900 hr on this date. The water was induced through the 4-in.-diam standpipe into the perforated pipe and gravel layer at the bottom of the sand fill. Approximately

6 hr were required to fill the gravel layer at the bottom of the sand before any water showed up in the piezometer tubes installed in the sand fill. By 0900 hr on 26 January 1978, items 1 and 4 were completely saturated with free water on the surface of the sand. The water level of items 2 and 3 was about 9 in. below the surface at this time as indicated by the piezometers. By 0900 hr on 27 January 1978, all test items were completely saturated.

51. The fully saturated sand was very loose and in a quick state and would not sustain any loading. None of the test items would support a man walking over the surface. The water content of the saturated sand was about 21 percent by dry weight. At this time, it was evident that the sand would require some drainage and densification before it would sustain any loading. Therefore, the standpipe at the sump where water was induced into the sand was cut off 8 in. below the elevation of the sand surface, which was about the bottom of the top layer of grid. This allowed the water drainage of the top layer of sand. Three days later on 30 January 1978, there was no free water on the surface, and some reduction in water content was indicated in the top 6 in. of the sand in items 1 through 4; but item 5, where the sand grid was placed over the Styrofoam insulation, was not draining and remained fully saturated. The only way drainage could occur in this item was horizontally as the insulation material was placed over a waterproof membrane, which would prevent vertical drainage. Therefore, a trench was excavated along the sides of this item down to the bottom of the Styrofoam layer to permit horizontal drainage. At the same time, the other sand items were drained to a depth of 15 in. below the surface of the sand.

52. On 1 February 1978, water content and density determinations were made in the top 6 in. of each test item, and airfield penetrometer readings were made in and below the sand-filled grids (Table 3). As can be noted, the water contents in top of the sand had decreased in all test items. However, the airfield penetrometer readings were very low for the sand inside the grids but increased in the sand below the grids. This was evidence that the density of the sand below the grid was much higher than for the sand inside the grid. Further, it is interesting to note

that in item 5 no reading was obtained on the airfield penetrometer for the full depth of the sand-filled grids and that the penetrometer sank to the bottom of the sand under its own weight. Since the overbuild of sand on top of the grids was about 2 in., it was decided to try to consolidate the sand with a D-4 tractor; but as soon as the tractor got onto the sand, the tracks penetrated down about 10 to 12 in. (Photo 37).

53. On 1 February 1978, the water level was lowered to 23 in. below the surface of the sand in items 1 through 4, and on 2 February 1978, an attempt was made to compact the sand with a D-4 tractor. The sand in item 1 sustained two passes of the tractor without damaging the grid. However, the tractor sank down in item 2 to a depth of 6 to 10 in. (Photo 38).

54. The water level was held at the 23-in. depth for about 5 days during which several attempts were made to consolidate the sand. On 3 February 1978 (Table 3), two complete coverages of the D-4 tractor were applied over test item 1 with no adverse effect. When extended into item 2, the tractor would sink up (Photo 39). As indicated in Table 2, the water content of the sand above the free-water table continued to decrease with time. However, the tractor or any other equipment running over the sand tended to pump the water to the surface. After two coverages of the tractor over item 1, on 3 and 6 February 1978, the sand would be spongy with free water on the surface. In item 2 where rutting occurred, free water would accumulate in the ruts (Photo 40).

55. In the initial efforts to consolidate the sand, the two layers of grid in item 2 were for practical purposes destroyed, and it was evident that compaction could not be obtained in any of the items to where they would support a C-130 aircraft loading so long as a high water table existed. Therefore, on 7 February 1978, the drain plug at the bottom of the section was removed permitting all free water to drain from the sand.

56. On 9 February 1978, some of the torn up grid in item 2 was removed, and the ruts were filled with additional sand and leveled to the original elevation. Two coverages of the D-4 tractor were then

applied over items 1 and 2. Water contents were taken at 6-, 12-, and 18-in. depths in items 1 through 4 and to a 12-in. depth in item 5. Table 3 lists the density and penetrometer readings that were also taken. These data indicated that the tractor compaction was resulting in some increase in density and penetration resistance in the sand-grid layers.

57. The weather was quite cold throughout the conduct of these tests and during the period 9 through 13 February 1978. The surface of the sand fill was frozen to a depth of about 2 in. By the afternoon of 13 February 1978, the sand had thawed, and four coverages of the D-4 tractor were applied over test items 1 through 4. The sand in item 5 was still quite wet and would not support the D-4 tractor (Table 3). On 14 February 1978, additional compaction was applied to test items 1 through 4 with a D-4 tractor, 25-ton pneumatic-tired roller, and a vibratory steel-wheel roller (Photos 41 and 42). This compaction effort resulted in a considerable increase in density and stability of the sand in items 1 through 4. Item 5 would not drain and was abandoned from the test.

Traffic Testing

58. On 21 February 1978, traffic was applied in a traffic lane 45 in. wide (three-tire-print widths) down the center of the test section (items 1 through 4). This traffic was applied with a load cart equipped with a 70-kip single-tandem gear load simulating one main gear of a C-130 aircraft.

Behavior under traffic

59. The first two passes of the load cart, forward and backward, in the same track left a rut varying from about 2 to 4 in. deep for the full length of the test section (Photo 43). Photos 44, 45, and 46, respectively, show a closeup view of rutting in items 1, 2, and 3 at the end of 100 coverages of traffic. As can be noted, the deformation was fairly uniform in each item, and the depth of ruts averaged about 7.5 in. in item 1, 8.5 in. in item 2, and 6 in. in item 3. The average rut depth in item 4 over the high-strength, stabilized base was about 6 in. as

compared with about 12 in. over the loose sand foundation (Photos 47 and 48). Traffic was continued to 200 coverages, which is equivalent to about 810 aircraft operations, with very little change in rut depth or appearance of items. By this time, the sand was highly consolidated, and the stability was adequate to sustain traffic indefinitely. Therefore, traffic was discontinued.

After-traffic evaluation

60. Water content, density, and airfield penetrometer readings were obtained in each test item for the sand inside the grids and below the grids (Table 3). From these data, it can be noted that the simulated C-130 traffic resulted in a substantial increase in density of the sand inside the grids and also some increase in density below the grids. Also, as the density increased, the strength increased as indicated by the higher airfield index values. The initial low stability of the sand was due to the low density and high voids of the sand as placed in the paper grids. The maximum density developed for this sand in the laboratory with the CE 55 blow compaction effort was 117.8 pcf at an optimum water content of 10.0 percent. Densities exceeding this value were developed in the test section by the simulated C-130 traffic.

61. Following the traffic testing, test trenches were excavated across the test items in order to evaluate the condition of the paper grids. Photos 49 through 52, respectively, show views of the test trenches in items 1, 2, 3, and 4. As can be noted in the photographs, the grid remained in the vertical position as placed, and the surface contour conformed to the contour of the surface of the sand in items 1, 3, and 4. The grid was badly torn up in item 2 during the initial efforts to consolidate the sand, and the contour of the grid could not be determined in this item.

62. Elevation readings were taken at the bottom of the grid layer during construction, on the surface of the sand as constructed, again after compaction, and at the end of traffic testing. With the C-130 test load cart, elevation readings were also taken in the test trenches at the top and bottom of the grid layers after traffic. Plate 10 presents the data for test items 1 through 3. From Plate 10a, it can be noted

that for item 1 the 6-in. layer of grid deformed to the same contour as the surface of the sand. The maximum deformation at the center of the traffic lane was about 7 in., and upheaval of the sand and grid surface occurred about 6 ft from the center of the traffic lane on each side. This indicates some lateral displacement of sand below the 6-in.-deep grid. Further, the 6-in.-deep grid compressed to about 5 in. under the loading.

63. Plate 10b shows more deformation in the surface of the sand than occurred in item 1; however, the two layers of 6-in. grid in item 2 were destroyed in the initial compaction effort, and the grids were not effective. There was also lateral displacement of the sand in this item as indicated by the upheaval of sand outside the traffic lane.

64. In item 3, three layers of 6-in. grid were placed with about 1 in. of sand between the layers making a total depth of about 20 in. of grid-confined sand. The maximum deformation in the surface of the sand from the 200 coverages of simulated C-130 traffic was about 6 in., which is less than items 1 or 2. Also, there was no indication of lateral displacement of the sand below the bottom of the sand grids. A thickness of the grid after traffic of about 18 in. indicated little or no compression of the grid.

65. In item 4 where two layers of grid were placed over a variable strength subgrade, trenches were cut over the high-strength foundation and over the loose sand foundation. In Plate 11a, a cross section over the firm foundation shows that the maximum deformation is about 4 in. with upheaval on each side of the traffic lane. The two layers of grid, which extended about 13 in. deep into the sand, initially were compressed to about 7 in. The upheaval in this case was primarily due to the excess sand on the top of the grids, which was displaced laterally by the traffic. Plate 11b shows a similar cross section of a trench over the loose sand foundation. These data indicate a maximum deformation in the center of the traffic lane of about 10 in. In this case, the loose sand underneath the grid is consolidating, and the grid is conforming to the consolidation. The upheaval indicated is due to lateral displacement of the surface sand on the top of the grid and not the sand below the grid.

66. Plate 11c shows a profile showing the deformation and position of the grid down the center of the traffic lane over the high-strength and low-strength foundation. As can be noted, the grid did conform to the differential settlement and remained in essentially vertical position as placed.

Test with Frozen Sand

67. If sand-grid-type construction is used in Alaska during the winter months, the sand will be frozen and will require breaking up and pulverizing prior to placement in the grids. It has been estimated that the sand available for construction will have a water content of about 20 percent in the frozen state. In order to get some information of the difficulties that may be encountered in pulverizing the frozen sand and filling the grids, a small quantity of the sand used in the test section was put in containers at a water content of about 20 percent dry weight and frozen in a freezer cabinet at a temperature of -40°F. After freezing overnight, the sand was broken up and placed in a small section of the 6- by 6- by 6-in. paper grid. The following paragraph describes this operation.

68. When removed from the freezing cabinet, the frozen sand resembled a block of ice (Photo 53). An ax was used to break the sand up into chunks (Photo 54), and the chunks were broken up to about 1-1/2-in. maximum size with a 10-lb compaction hammer. A small section of the 6- by 6- by 6-in. paper grid was expanded in a metal tray, and the crushed frozen material placed in the grids with shovels (Photo 55). There was only enough of the frozen material to fill about 12 of the grid compartments to about 1 in. above the top of the grid. After thawing, very little free water drained from the sand, and the thawed material settled about 1 in. into the grid but remained quite wet and soft for several days (Photo 56).

69. This experiment indicates that considerable effort may be required to pulverize frozen saturated sand in Alaska to where it could be placed in the grid sections and also that, when thawed, it would have

a very low stability until adequate drainage and compaction could be accomplished.

Conclusions

70. Based upon the results of this test section, the following conclusions are made:

a. A 6- by 6- by 6-in. paper grid as used in these tests will not confine a fully saturated loose sand adequately to sustain traffic of C-130 aircraft or vehicular traffic.

b. The grid restricts lateral drainage of sand; where placed over an impervious foundation, such as insulation over frozen material, the grid holds water in the sand and results in an unstable condition. Drainage may be improved by perforating the grid.

c. After drainage and drying to about optimum water content, the sand can be compacted in the grids to high densities with standard compaction equipment without damaging the grid.

d. A 12- to 18-in. depth of 6- by 6- by 6-in. grid-filled sand, highly compacted, will adequately confine the sand and prevent shear and lateral displacement of the sand below the grid layer under C-130 aircraft traffic.

e. A 6-in. depth of 6- by 6- by 6-in. grid is not adequate to prevent shear and lateral displacement of the sand below the grid.

f. The paper grid filled with sand over a variable strength foundation will conform to the settlement in foundation and still be effective in confinement of the sand.

g. The concept of using grids filled with saturated frozen sand is not considered feasible due to the difficulties in processing the sand, the very low density and high water content of sand after thaw, and the probability of very slow drainage.

PART V: TEST SECTION NO. 4, GRAVEL THICKNESS REQUIREMENTS TO PROTECT THE INSULATION

Background

71. From the test reported in Part III of this report, it was determined that a 20-in.-thick, good-quality gravel base course constructed over 60-psi Styrofoam insulation material would protect the Styrofoam from compression under C-130 aircraft loading. Also, a 10-in.-thick gravel base was found not adequate to protect the insulation under C-130 aircraft loading. The decision was made to use gravel over insulation for the runway construction at Inigok and Tunalik drilling sites. However, due to the high cost of quarrying and hauling gravel, it was desired to determine the minimum thickness of gravel required to prevent compression in the Styrofoam insulation under C-130 aircraft traffic.

Objective and Approach

72. The objective of this study was to determine the minimum thickness of good-quality gravel base course needed over 60-psi Styrofoam insulation material to prevent compression in the Styrofoam under C-130 aircraft operations. This was accomplished by the construction and traffic testing of a test section supported by an analytic analysis.

Description of Test Section

73. A layout of Test Section No. 4 is shown in Plate 12. The test section was 75 ft long by 25 ft wide and consisted of three test items, each 25 ft long. The design thickness of the base was 15, 17.5, and 20 in. for items 1 through 3, respectively. The test section was constructed under shelter in a hangar test facility. The subgrade consisted of a lean clay soil well compacted to produce a relatively high strength representing frozen material.

74. The insulation material used was a single layer of Styrofoam HI (60 psi) 2 in. thick obtained from Dow Chemical Company. The panels were 2 ft wide by 8 ft long and were part of a production quantity being made at Dow's Fort Saskatchewan, Canada, plant. A 6-mil polyethylene sheeting was placed between the Styrofoam and gravel. The membrane will be used in the actual construction to prevent water from getting to the permafrost layer below the insulation. The gravel used for subbase was a pit-run gravelly sand, the same as in previous test sections. The top 6 in. of base consisted of a well-graded, 1-1/2-in. maximum-size crushed limestone.

Construction

Subgrade

75. An area 75 ft long by 25 ft wide was laid out, and the existing soil in the area was excavated to a depth of about 17 in. below design surface elevation. The soil in the bottom of the excavation was processed and compacted to result in a relatively high strength (CBR of about 20). Steps were then cut in the subgrade to a smooth flat bottom to provide for the 2-in.-thick insulation and base thickness of 15, 17.5, and 20 in., respectively, for test items 1 through 3. Photo 57 shows a general view of the prepared subgrade.

Instrumentation and placement of insulation

76. Two of the Styrofoam panels in each test item were instrumented with DCDT gages manufactured by G. L. Collins Corporation, Long Beach, California, in order to monitor the displacement and compression in the panels during the application of traffic. The gages were mounted onto the Styrofoam panels by drilling a small diameter hole through the Styrofoam and gluing a thin aluminum (0.063 in.) plate 12 by 12 in. square to the bottom of the foam to which the probe housing was attached (Photo 58). A 3-in.-diam hole was then excavated into subgrade to receive the housing (Photo 59). Loose sand was poured into the holes around the housing during placement of the insulation. The lead wire

from the gages was placed on top of the subgrade leading to the east side of the section underneath the insulation. A 2-in.-diam, 0.063-in.-thick aluminum disk was attached to the top of the Styrofoam panel to which the gage probe was attached. The gages were set to show displacement of $\pm$ 0.75 in. All instrumented Styrofoam panels were placed in the center of the traffic lane (Photo 60). The remaining insulation panels were placed around the instrumented panels with a staggered joint pattern (Photo 61). The 6-mil polyethylene membrane was then spread over the insulation panels (Photo 62).

Gravel base

77. The gravelly sand subbase was placed in a single lift of sufficient thickness to result in a compacted lift thickness of slightly more than the desired subbase thickness for each item--9, 11.5, and 14 in. for items 1, 2, and 3, respectively. The material was end dumped onto the polyethylene sheeting (Photo 63) and spread with a front-end loader and motor grader (Photos 64 and 65). The subbase material was compacted with a 50-ton pneumatic-tired roller with tire pressure of 60 psi (Photo 66). After compaction, the subbase was graded to the desired grade. The top 6 in. of base consisted of a 1-1/2-in. maximum-size crushed limestone. Plate 13 presents the classification data for the limestone base. The CE 55 blow laboratory compaction test resulted in a maximum density of 146.4 pcf at an optimum water content of 4.7 percent. The material was placed and compacted in a single lift using the same pneumatic-tired roller except that the tire pressure was increased to 90 psi. The as-constructed density was about 95 percent of the CE 55 maximum. Photo 67 shows a general view of the completed section.

Traffic Testing

78. A total of 14 patterns of traffic, 480 passes, was applied in a 75-in.-wide traffic lane resulting in 280 coverages of a loaded tire in the center 45 in. of the traffic lane or an equivalent of 1134 C-130 aircraft operations. This traffic had very little effect on the appearance of the section with the exception of slight deformation in each

item. Photos 68, 69, and 70, respectively, show a general view of items 1, 2, and 3 at the end of 480 passes of traffic.

79. The DCDT gages, which were installed in the Styrofoam insulation, were read continuously during the period of traffic and did not indicate any significant compression of the insulation material in any of the test items. Only very slight elastic deflections about 0.005 in. were indicated as a wheel passed over a gage, and then it would rebound to its original thickness.

80. At this time, an observation pit was excavated in item 1 (15-in. thickness over insulation) to observe the condition of insulation. Photo 71 shows a view of the pit with gravel removed to the top of the membrane. It can be noted that the polyethylene membrane is intact with no visible holes or tears. The membrane was then removed to expose the Styrofoam insulation (Photo 72). The insulation appeared to be in good condition except for shallow pitting in the top of foam where gravel was embedded into the Stryofoam to a depth of 0.25 to 0.50 in. A section of the Styrofoam about 12 in. square was removed to measure the thickness. The overall thickness was found to still be about 2 in. or the original thickness as placed.

81. Based upon the satisfactory performance of all items with 15- to 20-in. thickness over insulation, it was decided to remove the 6-in. crushed stone in order to reduce the thickness of gravel over insulation to 9.0, 11.5, and 14 in. for items 1 through 3, respectively, and then to continue traffic with the C-130 test load cart to determine the minimum thickness required to prevent compression in the insulation material.

82. After removal of the top 6 in. of the base course, 20 passes of the load wheels were applied in a single-wheel path down the center of the traffic lane directly over the gage installations. The gage reading showed slight compression in the Styrofoam beginning with the first pass in item 1, which increased with an increase in the number of passes. By the end of 20 passes, the gage reading indicated slight compression of the foam in all test items. Forty-eight additional passes were applied following the original traffic pattern for the 75-in.-wide traffic lane.

At the end of this traffic, the DCDT gages indicated compression of the Styrofoam to be about 0.25, 0.125, and 0.06 in., respectively, in test items 1, 2, and 3, and no further traffic was applied. Photos 73, 74, and 75, respectively, show a general view of the surface of each item at the end of traffic for test items 1, 2, and 3.

After-traffic inspection

83. Test trenches were excavated in each test item over and adjacent to the gage installations in order to examine the Styrofoam panels and gages. Photo 76 presents a view of the Styrofoam in place in test item 1 showing the smooth texture of the surface around the gage in the upper right of the photograph and the pitted surface away from the gage. The pitted surface was caused by gravel being embedded into the surface of foam, whereas a thin layer of sand placed over the gage during construction protected the Styrofoam from the gravel. Photo 77 shows a section of the Styrofoam cut from item 1. Thickness measurements on this section showed the actual thickness was reduced from the original thickness of 2.0 in. to an average of 1.05 in. This is a greater compression than indicated by the gage. When the gage was removed from the section, it was determined that the aluminum plate to which the gage housing was attached on the bottom of the Styrofoam had deformed into the hole in the subgrade; therefore, the gage was not giving a true reading of the magnitude of compression in the foam. This same behavior occurred with all the gage installations.

84. The trench in test item 2 revealed a break in a Styrofoam panel near the center of the traffic lane (Photo 78). Thickness measurements on the section of Styrofoam cut from item 2 showed a reduction in thickness of about 0.25 in. The measured compression in the Styrofoam cut from item 3 was also 0.25 in. Photo 79 shows a closeup view of Styrofoam sections cut from items 1, 2, and 3.

Deformation

85. Cross sections were taken on the surface of the base at stations corresponding to the DCDT gage locations in each item prior to traffic and after traffic to show rutting and permanent deformation of the gravel base course. Data were compiled for the original section

and for the reduced thickness after removal of the 6-in.-thick crushed stone base course. Cross section plots in Plate 14 show deformation in item 1 at gage locations 6 and 5 with the initial 15-in. thickness and after removal of the top 6-in. crushed stone base. Similar plots in Plates 15 and 16 show surface deformation in test items 2 and 3, respectively.

Summary of traffic test results

86. The CBR, water content, and density of the crushed stone base, gravelly sand subbase, and lean clay subgrade as constructed (zero coverages) and after traffic are summarized in Table 4. Also, the total thickness of base over insulation, traffic applied, and compression of Styrofoam insulation are indicated. From these data, it can be noted that no measurable compression occurred in the Styrofoam with 15 in. or more base over the insulation. However, some compression occurred in all items with less than 15-in. thickness. Further, the traffic caused an increase in density and strength (CBR) of the base course resulting in some reduction in thickness of base from the original thickness prior to traffic.

Analytical Analysis

87. A mechanistic analysis approach was used to estimate the thickness of cover required above the polystyrene insulating layer. This approach determined the elastic properties (modulus of elasticity (E) and Poisson's ratio) of the pavement components, which were then used in an analytical model (computer program based upon layered-elastic theory) to estimate the distribution of stresses within the section. The strength of the polyestyrene was compared with the computed stresses to predict the cover required for the protection of the insulating layer.

Determination of material properties

88. The structural properties of expanded polystyrene insulating material were previously investigated and reported in WES Technical Report S-74-8.* The previous study included a polystyrene identified as Styrofoam HI, which was the same designation as the polystyrene material used for this study, and the test results compiled by Barker and Parker* were to be used for this analysis. Tests conducted on the Styrofoam HI material in the previous study included unconfined compression with both single and repeated loadings and CBR (small plate bearing tests). Plates 17 through 19 present the results of these tests, along with the results of tests conducted on a 4-CBR clay (CH), as shown in Technical Report S-74-8.

89. The Styrofoam HI panels used for the previous study were 4 in. thick; whereas, the panels for this study were 1-1/2 and 2 in. thick. A laboratory test program was conducted to assure that the properties of the Styrofoam HI material shown in Technical Report S-74-8 were the same as the properties of the Styrofoam HI material used for this study. Single-loading unconfined compression tests were conducted on these samples from each of the two-panel thicknesses and on a single sample constructed by gluing three thicknesses of the 2-in. panels to form a specimen 6 in. high. All samples were approximately 3 in. in diameter. The purpose of the 6-in.-high specimen was to evaluate the effect of height-to-diameter ratio. Table 5 presents the results of these tests. The stress-strain curves for the three specimens from each panel thickness were sufficiently close that an average curve was developed for each panel thickness and are shown along with the stress-strain curve for the 6-in. specimen in Plate 20.

90. Repeated-load unconfined compression tests were conducted on three specimens from the 2-in.-thick panel of Styrofoam HI material to establish a resilient modulus for the material. Table 6 shows the results of these tests.

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* W. R. Barker and F. Parker, Jr., "Comparative Performance of Structural Layers in Pavement Systems, Vol IV, Analysis of Insulating in Pavement Test Sections," Technical Report S-74-8, Jan 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

91. CBR tests were performed on large sections of both the 1-1/2- and 2-in.-thick Styrofoam HI material. Although these tests were conducted in the laboratory, they were conducted in a manner to simulate the field CBR. The measured CBR values at 0.1-in. piston penetration were 8, 7, and 9 for the 2-in.-thick material and 8, 7, and 7 for the 1-1/2-in.-thick material. Plate 21 shows the typical load-penetration curves.

92. The results of the laboratory tests indicate no significant difference between the material tested and reported in WES Technical Report S-74-8 and the Styrofoam HI material used for this study. Within the linear stress range (below about 60 psi), the thickness of the panel had little influence on the material behavior; however, the ultimate strength of the material decreased as the thickness of the material was increased. Interestingly, the unit piston pressure corresponding to the CBR's of 7-8 (Plate 21) compare well with the unconfined compression strength (Plate 20) of the Styrofoam HI. This indicates that the Styrofoam HI has properties approaching that of a Winkler foundation, i.e., the properties of a bed of independent springs. This behavior is in contrast to that of a clay material that might have an unconfined compressive strength of only 12 psi yet have a measured CBR of 4 to 5, which would correspond to a unit piston pressure of 40 to 50 psi. Considering the Styrofoam HI, to behave as a Winkler foundation means that the structural performance can be directly related to the applied vertical stress and to the compressive strength of the material.

93. Based upon the data available, a modulus of elasticity (E) of 4000 psi is believed reasonable for the Styrofoam HI material. Since the materials behave as a Winkler foundation, the Poisson's ratio would be zero. The unconfined compression tests indicate some nonlinear behavior beginning at a stress level between 50 and 60 psi; however, severe crushing of the Styrofoam HI material did not occur until the stress level reached 65 to 70 psi.

94. No laboratory tests were conducted on the subgrade or granular material to be used over the Styrofoam HI material. The test section subgrade was a dry, well-compacted lean clay material used to represent

a frozen subgrade condition for the prototype. Both the dry CL and the frozen subgrade would exhibit very high-moduli values, and a value of 500,000 psi was assigned for this analysis. From previous experience, a Poisson's ratio of 0.3 was assigned to the CL subgrade. The behavior of granular materials requires the use of quasi-elastic properties, which seem to be dependent upon the modulus of the underlying material and the thickness of the granular layer. This concept was used for the development of design criteria for flexible airport pavements (Plate 22).* Since the granular material used for this study was a pit-run gravel, the modulus curves in Plate 22 for subbase material were used to select moduli values for this analysis. For example, assume that 15 in. of subbase are to be placed on the Styrofoam having an E value of 4,000 psi. The 15-in. thickness should be subdivided into two layers 8 and 7 in. thick. Then, from Plate 22, the E value for the 7-in. (n) layer would be 9,200 psi based upon the E value of the Styrofoam HI (n + 1) layer of 4,000 psi. Similarly, the E value of the 8-in. upper layer of gravel would be 17,000 psi. Based upon data given by Barker and Brabston,* the Poisson's ratio of the pit-run gravel was selected as 0.3.

Aircraft loading

95. The loading used for the analysis was 35 kips applied uniformly over a circular area having a radius of 10.5 in. selected to simulate a loaded C-130 aircraft tire. The resulting unit pressure for the load was 100 psi. In such a simulation, it is assumed that no interaction occurs between any two wheels of the main gear of the aircraft. This is considered to be a reasonable assumption for aggregate surfacings and for the single-tandem main gear wheel configuration of the C-130 aircraft.

Determination of stress distribution

96. The Shell Oil Company's BISAR computer program was used to compute the distribution of stresses in the pavement section under the

* W. R. Barker and W. N. Brabston, "Development of a Structural Design Procedure for Flexible Airport Pavements," Technical Report S-75-17, Sep 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

selected circular loaded area representing the aircraft wheel. Three separate cases were studied with the thickness of Styrofoam HI material held constant at 2 in. for each case. Case I assumed all materials to have the same elastic properties, i.e., a Boussinesq stress distribution was assumed. Although the stress distribution will be the same regardless of values used for the elastic properties for this assumption, an E value of 4,000 psi was used for the computation. Case II considers the subgrade to be very stiff (E = 500,000 psi) representing a frozen subgrade, and all materials above the subgrade (Styrofoam HI and gravel) were assumed to have an E value of 4,000 psi. For Case III, the subgrade was considered to be very stiff (E = 500,000 psi) representing a frozen condition, and an E value of 4,000 psi was used for the Styrofoam HI material; the E value for the gravel overlayment was determined from Plate 22 depending upon the thickness and number of layers used. For these computations, the gravel overlayment was always divided into two layers of approximately equal thickness. The stress at the top of the Styrofoam HI material for various thicknesses of gravel overlayment is shown in Plate 23 for all three cases.

Prediction of required thickness of gravel

97. The required thickness of gravel to protect the insulation material from excessive permanent deformation can be predicted for each of the three cases studied using the data presented in Plate 23. As mentioned in paragraph 93, there was evidence of nonlinear behavior at a stress level between 50 and 60 psi from the laboratory unconfined compression tests. If a value of 55 psi is selected as an allowable stress for the Styrofoam HI material, the required thickness of gravel from Plate 23 is found to be 12.8, 16.2, and 15.1 in. for Cases I, II, and III, respectively.

98. A comparison of the predicted thickness requirements with the performance data from the actual traffic tests indicates that Case III provides the best prediction of cover thickness requirements. As stated in paragraph 86, no permanent deformation was detected when the thickness of gravel cover was 15 in. or more. When the thickness of gravel cover

was reduced to less than 15 in., permanent deformation (crushing) of the Styrofoam HI material occurred rapidly under traffic. Based upon this data, the Case III predicted thickness agrees most closely with the performance data.

Conclusions and Recommendations

99. Based upon the results of tests and analysis reported herein, the following conclusions are believed warranted:

- a. The analytical analysis using the Case III assumptions appears to be a valid method for determining the required thickness of gravel cover to protect the insulation material from detrimental crushing.
- b. A minimum thickness of good-quality, well-compacted gravel of 15 in. will protect the Styrofoam HI (60 psi) insulation material from detrimental crushing under C-130 aircraft traffic.
- c. Gravel placed directly on the Styrofoam HI insulation material will partially embed into the Styrofoam to a depth of 0.25 to 0.50 in. The effect that this embedment will have, if any, on the insulating quality of the Styrofoam was not evaluated.

100. For the design and construction of gravel cover on Styrofoam HI material to keep the subgrade frozen as a facility for C-130 aircraft operations, the following are recommended:

- a. The surface of subgrade upon which the insulation material is placed should be graded as smooth as practicable to minimize bridging of the insulation and with no protruding rocks or sharp objects that would damage the insulation.
- b. A waterproof membrane should be placed on top of the insulation to prevent infiltration of water to permafrost material.
- c. The gravel used directly over insulation should be well-graded, uncrushed material with maximum size of 1-1/2 in. or less.
- d. The first lift over insulation should be at least a 12-in. thickness and placed by end dumping, which starts at one edge of insulation and is spread with a light dozer, front-end loader, or motor grader with the equipment working on the covered material.

e. Compaction should be accomplished with vibratory smooth-wheel rollers and pneumatic-tired rollers with a tire pressure of not more than 60 psi.

f. According to the test results reported herein, the minimum thickness of 15 in. of gravel is required to protect the Styrofoam from compression. However, to provide some safety factor and to allow for traffic consolidation and construction variations, it is recommended that a compacted thickness of 18 in. of gravel base be used over the 60-psi Styrofoam HI insulation.

g. Should other grades of Styrofoam insulating materials, the quality of granular overlay material, or other aircraft loadings be anticipated than those used for the traffic tests reported in this study, it is recommended that the required thickness of material to protect the insulation material be determined analytically using the Case III assumptions stated herein.

PART VI: TEST SECTION NO. 5, SAND-GRID ROAD CONSTRUCTION TEST SECTION

Background

101. Tests previously conducted with paper grids filled with loose saturated sand for possible application in construction of airfields at the NPRA drilling sites indicated that the grids would not adequately confine a fully saturated loose sand to sustain C-130 aircraft operations. However, after the excess water was drained and the sand densified, the stability was adequate to sustain C-130 aircraft traffic (see Part IV, Test Section No. 3). This behavior indicated that the sand-grid concept may have application for road construction at the drilling sites, provided the construction could be accomplished during the thaw season and the sand compacted in the grids.

Objective

102. The objective of this study was to evaluate the concept of sand-grid confinement for road construction at the NPRA drilling sites using relatively dry dense sand similar to that which is available at the drilling sites. Specific objectives were to determine the effect of grid cell size and to compare the load-carrying capacity of the compacted sand with and without grids.

Description of Test Section

Layout

103. A layout of the test section is shown in Plate 24. The test section consisted of a compacted sand fill 18 in. thick and 120 ft long by 25 ft wide. The section was divided into four test items, each 30 ft long. For test items 1, 2, and 3, a single layer of paper grid that was 6 by 6 by 6 in., 8 by 8 by 6 in., and 12 by 12 by 6 in., respectively, was placed in the top 6 in. of the sand fill. In item 4, no grid was used.

Construction

Subgrade

104. The subgrade consisted of a lean clay soil, which was processed and compacted to result in relatively high strength, CBR 20, to represent a permanently frozen material. The compacted subgrade was graded to a flat level surface at the same elevation as the hangar floor.

Sand fill

105. The bottom layer of sand was end dumped onto the prepared subgrade and spread with a D4 tractor (Photo 80) to provide a 12-in.-thick compacted layer. Compaction was accomplished with a 50-ton pneumatic-tired roller with tires inflated to 60 psi.

106. The paper grid was expanded on the top of the 12-in. compacted sand fill. The expanded grid was then filled by end dumping sand onto the grids (Photo 81) and spreading it over the grids (Photo 82). Photo 83 shows a general view of filling the 12- by 12- by 6-in. grid in item 3. The top 6 in. of sand in item 4 was placed with no grid. For all grid-filled items, it was necessary to overfill some 4 or 5 in. to protect the grids from damage of equipment working over them. After the filling of the grids, the excess sand was bladed off (Photo 84), leaving a thickness of 1-1/2 to 2 in. cover on the top of the grids. The sand was then compacted by eight coverages of the 50-ton pneumatic-tired roller (Photo 85).

Traffic Testing

Truck traffic

107. Photo 86 shows a general view of the test section prior to traffic. The initial traffic was applied with a 40-kip, 6 x 6 military truck (Photo 87). Traffic was applied by driving the truck forwards and backwards in essentially the same tracks down the center of the test section for 100 passes of the truck, which is equivalent to about 300 passes of a single 18-kip axle load. This traffic had no detrimental effect on any of the test items. Photo 88 shows a general view of the test section at the end of this traffic.

C-130 aircraft loading

108. Due to the excellent performance of all test items under the truck traffic, it was decided to apply additional traffic with a C-130 aircraft loading. Traffic was applied with a 70-kip, single-tandem gear test load cart simulating one main gear of a C-130 aircraft (Photo 89). The traffic was distributed uniformally over the center 45 in. of the test section (three-tire-print widths) for a total of 300 passes, an equivalent of about 810 aircraft operations. This traffic resulted in only minor rutting in the sand surface over the grids and slightly less rutting in the surface of sand in item 4 where there were no grids. The most pronounced rutting was about 2-1/4 in. in test item 2, which had the 8- by 8- by 6-in. grid. The least rutting was less than in items 1 and 4. Photos 90 and 91, respectively, show items 1 and 4 at the end of traffic.

109. The performance of the sand under traffic was much better than had been anticipated. The entire section was quite stable, and it was evident that it would sustain traffic indefinitely with the C-130 loading. The sand had dried to below optimum and was slightly dusty on the surface. It was decided to wet the sand and see if wetting would affect the load-carrying capability. The sand was wetted down with a metered water hose over a period of about 1 hr with a quantity of water equivalent to about a 0.5-in. rainfall over the surface area of the test section. This water essentially saturated the sand to a depth of 6 to 8 in. During the watering operation, water ponded on the surface and in some cases ran over the shoulders of the sand fill resulting in rapid erosion of the sand slopes. After wetting, approximately 50 passes of additional traffic were then applied to the test section, resulting in no change in the condition of the section. Photo 92 shows an overall view of the test section after wetting and C-130 traffic with item 1 in the foreground. This verified that the compacted dense sand will remain stable after saturation.

110. In order to try to develop a failure in the sand section, additional traffic was applied with an F-4C aircraft loading. The F-4C loading was simulated with a single-wheel load test cart loaded to

25 kips and a tire pressure of 250 psi. The cart was powered by the front end of a four-wheel drive truck. The first pass of the load cart resulted in a rut about 1-1/2 in. deep in items 1 and 4 and about 2-1/2 in. deep in items 2 and 3. The cart became immobilized in the 2-1/2-in. rut in item 2 (Photo 93) and required some assistance from a forklift to get it moving. The disturbed area on each side of the center line was caused by the traction wheels of the front-wheel drive power unit. Photo 94 shows an overall view of the section after about four passes of the load wheel.

After-traffic evaluation

111. At the conclusion of traffic, the excess sand was cleaned off to the surface of the grid for inspection of the grid. A view of the top of the 6-in. grid in Photo 95 shows the grid is in good condition with no apparent damage. The thickness of the sand over the grid was about 1-1/2 in. In item 2, the thickness of the sand over the grid was about 2-1/2 in.; and when cleaned off, some of the 8- by 8- by 6-in. grid was bent over at the top (Photo 96). This probably occurred during construction. Also, some folding of the 12- by 12- by 6-in. grid in item 3 was indicated in Photo 97. However, the grid was generally in good condition. The thickness of sand over grid in item 3 was about 2 in.

112. Vertical trenches were cut through the grid and sand fills down to the underlying subgrade. In-place CBR, water content, and density determinations were made at the surface of the sand-filled grids and in the sand at depths of 6 and 12 in. below the surface of the grid and also in the underlying lean clay subgrade. In-place tests were also made at the same elevations in test item 4 without grid. Photos 98, 99, and 100, respectively, show a view of the test trenches with the grid in place in items 1, 2, and 3. Table 7 summarizes the results of the in-place testing.

Discussion of test results

113. The performance of the sand in item 4 (no grid) under traffic indicates that when the sand is adequately compacted it is quite stable and will provide adequate bearing capacity to support highway vehicles or C-130 aircraft loading without the use of grid confinement.

Actually, rutting under traffic with the C-130 and F-4C load carts was slightly less in item 4 than in items 2 and 3 where the 8- by 8- by 6-in. and 12- by 12- by 6-in. grids, respectively, were used. However, the CBR and density data taken after traffic (Table 7) show that higher densities and strength (CBR) were developed in all fill items where the grids were used than in item 4 without grid. This indicates that the grids were effective in confining the sand and may be quite beneficial in a less stable sand. It is felt that the slightly greater rutting in items 2 and 3 was due to some folding over of the top of grids and movement of the unconfined sand on top of the grids.

114. There were no difficulties encountered in placing the paper grids and filling with sand. However, the 12- by 12- by 6-in. grid was easier to expand and fill with sand than were the 6- by 6- by 6-in. or the 8- by 8- by 8-in. grids. It was necessary to overfill the grids some 4 or 5 in. with loose sand to prevent damage from construction equipment working over the grids.

115. In a related research and development study being conducted for the Office, Chief of Engineers, entitled "Trafficability Enhancement Systems," several different sizes of aluminum grids are being evaluated to determine their effectiveness in improved trafficability over sands. For this study, the grids were installed in the upper portion of a compacted sand fill consisting of wet concrete sand with no fines (material passing No. 200 mesh). In order to compare the performance of the paper grid with the aluminum grid, two items were added, one of which included the 8- by 8- by 6-in. and 12- by 12- by 6-in. Hexcel paper grids. A control item was also placed with no grid.

116. This section is being traffic tested with a 40-kip, 6 x 6 military truck. After 10 passes of the truck, the item without grid had developed ruts 11 in. deep and was considered failed. The 12- by 12- by 6-in. paper grid completely tore up during the first few passes of the test truck, and after 10 passes the rutting was the same as the item without grid. The item with the 8- by 8- by 6-in. paper grid withstood 75 passes of the truck before reaching a rut depth of 11 in. At this time, the paper grid in the wheel paths was completely torn up. All the

items with aluminum grids performed much better than the paper grid, and some items are still in a satisfactory condition after 5000 passes of the truck traffic. Traffic is continuing, and the results will be reported in detail in a later report. The problem with the paper grid appears to be insufficient tear strength to confine the sand, especially in a wet environment. Even though the paper was treated with a phenolic resin, it absorbs water resulting in a loss in strength.

Conclusions

117. Based upon the results of tests reported herein, the following conclusions are believed warranted:

a. The paper grids can be placed and filled with sand using conventional construction equipment without damage to the grids. However, it was necessary to overfill the grids some 4 or 5 in. to protect them from damage of the construction equipment working over them.

b. The sand used in this study developed adequate strength when compacted to support highway loading and C-130 aircraft loading without the grid confinement; therefore, no apparent benefit was gained from the grid installation.

c. The in-place density and CBR of the grid-confined sand were higher at the end of traffic than was the unconfined sand in item 4. This indicates that the grids may be beneficial when used in a less stable sand. However, later tests conducted with the 8- by 8- by 6-in. and 12- by 12- by 6-in. paper grids in an unstable sand showed little or no benefits (see paragraph 116).

PART VII: SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Findings

118. Pertinent findings from the test conducted and reported herein are as follows:

- a. The XM19 aluminum landing mat placed over a 3-in. thickness (two layers, 1-1/2-in.-thick panels) of 60-psi Styrofoam insulation material, which was on a firm subgrade representing frozen material, was subjected to the equivalent of 850 C-130 aircraft operations with little or no detrimental effects on mat or insulation material.
- b. Good-quality gravel base courses of 15-in. thickness or greater over 60-psi Styrofoam insulation material, placed on a firm subgrade representing frozen material, withstood the equivalent of up to 1134 C-130 aircraft operations with no measurable compression of the Styrofoam material. With a base thickness of less than 15 in., some crushing of the Styrofoam occurred.
- c. Gravel placed directly on the Styrofoam material was partially embedded into the Styrofoam under the simulated C-130 aircraft traffic to a depth of 0.25 to 0.50 in. The effect that this embedment will have, if any, on the insulation properties of the Styrofoam is not known.
- d. A 20-in.-thick gravel base course over a fully saturated loose sand resulted in high deflections under simulated C-130 aircraft traffic. Rutting and displacement of the base course required frequent maintenance. However, when sand was allowed to drain to a depth of 6 to 18 in. below the surface of the sand, the base course and sand densified and stabilized under traffic. Traffic was continued for an equivalent of 810 C-130 aircraft operations.
- e. The Hexcel paper grid used in Test Section No. 3 was not effective in improving the stability or load-carrying capacity of a saturated loose sand. However, after the free water was drained from the sand, it was adequately compacted by static and vibratory rollers so that it would sustain traffic with a C-130 aircraft.
- f. The paper grid has some adverse effects in that it restricts lateral drainage of the sand; and where placed

over an impervious foundation, such as insulation or frozen material, the grid holds water in the sand and results in an unstable condition.

g. The sand used in the various test sections has gradation, permeability, compaction, plasticity, and other properties quite similar to that of representative samples of the borrow sand furnished from the Inigok drilling site. The results from Test Section No. 5 revealed that the sand used in the section developed adequate strength and stability when compacted at optimum water content to support C-130 aircraft or vehicular truck traffic without grid confinement. In fact, the sand fill without grid performed as well or better than where the grids were installed.

h. More recent tests, as discussed in Part VI, have demonstrated that the Hexcel paper grid used in these tests does not have sufficient tear strength to adequately confine an unstable sand in a wet environment to sustain aircraft or vehicular traffic.

Conclusions

119. The following conclusions are based on the findings of tests reported herein:

a. The XM19 aluminum landing mat placed directly over a sufficient thickness of 60-psi Styrofoam insulation material to prevent thaw in the frozen subgrade will provide a satisfactory runway for C-130 aircraft operation.

b. A minimum thickness of 15 in. of good-quality, well-compacted gravel will protect 60-psi Styrofoam HI insulation material from detrimental compression or crushing under C-130 aircraft traffic.

c. A 20-in.-thick gravel base course over a frozen sand fill without insulation would be marginal at best for C-130 aircraft operations after the sand thaws, depending upon how well the sand drains. With the sand fully saturated, an unstable condition may exist. However, if the sand drains and consolidates as it thaws, stability could be maintained by surface compaction and maintenance of the gravel surface.

d. The Hexcel paper grids used in these tests will not confine a fully saturated loose sand adequately to sustain traffic of C-130 aircraft or vehicular traffic.

_e_. For the sand used in these tests, which is similar to the borrow sand at the Inigok drilling site, adequate stability to support C-130 aircraft operations or vehicular traffic can be obtained by compaction of the material at optimum water content. Therefore, grid confinement is not needed. Additional tests with the Hexcel paper grid in an unstable sand have shown that this paper grid does not have sufficient tear strength to adequately confine an unstable sand in a wet environment for aircraft or vehicular traffic.

Recommendations

120. Recommendations for airfield construction in the NPRA are as follows:

_a_. For wintertime construction of runways capable of supporting C-130 aircraft during the thaw period, it is recommended that the concept of using insulation to prevent thaw in the subgrade be applied and that the insulation be overlaid with prefabricated landing mat or an adequate thickness of good-quality gravel base to protect the insulation material from compression.

_b_. Detailed procedures for construction of gravel bases over Styrofoam insulation are given in paragraph 100. The preparation of subgrade and placement of insulation for mat surfacing would be the same as for gravel surfacing. However, if mat surfacing is used, it would have to be properly anchored at the ends and along each side of the runway.

_c_. If any construction can be accomplished during the thaw period, it is recommended that a test fill be constructed with the fine Inigok sand compacted at optimum water content to the maximum practical density. Good compaction should be obtained using heavy vibratory or pneumatic-tired rollers.

_d_. The concept of using sand-grid confinement systems for airfields and roads is considered feasible where unstable sands exist. However, the Hexcel paper grids tested do not have adequate strength in a wet environment to properly confine the sand. It is recommended that further research be conducted to develop an improved grid, possibly using a different type paper, glue, and resin.

Table 1

Summary of Water Content and Density Data of Base Course Material After Traffic, Test Section No. 2

Test Item	Depth in.	Water Content percent	Dry Density pcf	Percent CE 55
1	0-5	3.3	133.5	102
	10-15	6.1	--	
	18-23	6.6	--	
2	0-5	3.7	134.0	102
	10-15	6.5	--	
	18-23	6.8	--	
3	0-5	4.9	133.0	101
	10-15	5.9	--	
	18-23	7.6	--	

Table 2

Sand Drainage Study - Summary of Traffic Test Data, Test Section No. 2

Test Item	Sand After Traffic: Depth from Surface of Sand in.	Sand After Traffic: Water Content percent	Sand After Traffic: Dry Density pcf	Traffic: Test Load	Traffic: Passes	Coverages	Equivalent C-130 Operations	Maximum Deformation in.	Remarks
1				35-kip single wheel*	40	7	28	0.4	
20 in. of					210	35	142	0.7	Surface repair of base
gravel					714	120	486	1.0	
over 6 in.				70-kip single tandem**	20	13	52	0.4	
of sand					72	48	194	0.8	No maintenance required
	Surface	10.5	106.0		300	200	810	1.0	
2				35-kip single wheel*	22	4	16	1.3	Surface repair of base
20 in. of				70-kip single tandem**	20	13	52	0.9	
gravel					72	48	194	3.2	
over 36 in.	Surface	14.2	--		250	167	676	3.5	
of sand	12	12.9	--						
	22	15.3	--						
	Surface	9.9	105.5		300	200	810	3.6	Free water drained at end of traffic
	12	11.4	105.4						
	22	16.1	102.3						
3				35-kip single wheel*	22	4	16	1.3	Surface repair of base
20 in. of				70-kip single tandem**	20	13	52	0.7	
gravel					72	48	194	2.5	No maintenance required
over 36 in.	Surface	10.4			250	167	676	2.8	
of sand	12	14.6							
	24	14.9							
	Surface	11.7	105.3		300	200	810	2.8	Free water drained at end of traffic
	12	12.5	103.1						
	24	14.9	101.8						
	36	14.4	--						

NOTE: Sand placed in section at an average water content of 7.2 percent and dry density of 102.0 pcf.

*Traffic applied with water level held at top of sand.

**Traffic applied with water level held 6 in. below top of sand.

Table 3

Sand-Grid Confinement Study - Summary of Events and Test Data, Test Section No. 3

Date	Test Item	Water Level From Surface in.	Compaction and Traffic Coverages	Water Content Percent Dry Weight 6 in.	12 in.	18 in.	Dry Density pcf In Grid	Below Grid	Airfield Index* Surface	6 in.	12 in.	18 in.	Remarks
1-25-78	1-5	Surface sand	0	21	21	21	94 to 98	110.9	0	-	-	-	Sand fully saturated-very unstable
1-30-78	1	8	0	19.6	-	-	94.1		0	7	7	8	
	2	8	0	17.8	-	-	95.1		0	0	0	8	
	3	8	0	15.7	-	-	95.9		0	0	0	0	AI = 9 below grids
	4	8	0	14.9	-	-	97.9		0	0	0	6	Two-layers grid over sand
	5	8	0	20.7	-	-	88.6		0	0	0	-	Styrofoam insulation at 14-in. depth
2-1-78	1	15	0	19.0	-	-	94.1		1	3	5	5	
	2	15	0	16.5	-	-	96.1		0	0	0	4	
	3	15	0	12.9	-	-	98.8		1	2	0	0	
	4	15	0	11.9	-	-	98.5		2	2	0	10	Two-layer grid over sand
	5	15	0	13.7	-	-	92.3		1	1	0	-	
2-2-78	1	23	D-4, 2 passes	13.6	-	-	104.3		1	3	3	5	Density and AI taken in dozer track
	2	23	D-4, 2 passes	12.7	-	-	99.4		0	0	0	4	
	3	23	0	11.9	-	-	100.1		1	2	0	0	AI = 10 below grids
	4	23	0	10.5	-	-	102.6		2	2	0	10	
	5	15	0	13.7	-	-	93.0		1	1	0	-	
2-3-78	1	23	D-4, 2 coverages	12.9	-	-	104.9		1	3	3	5	
	2	23	D-4, 2 passes	12.4	-	-	99.2		0	0	0	4	
	3	23	0	10.9	-	-	98.8		2	2	0	0	AI = 10 below grids
	4	23	0	10.6	-	-	101.9		2	2	0	9	Two-layer grid over sand
	5	15	0	13.0	-	-	92.5		1	1	0	-	
2-6-78	1	23	D-4, 2 coverages	11.6	-	-	105.1		2	5	5	8	
	2	23	D-4, 2 passes	11.3	-	-	98.9		1	2	0	8	
	3	23	0	8.8	-	-	100.0		2	2	0	7	AI = 10 below grids
	4	23	0	9.9	-	-	100.5		2	2	0	10	Two-layer grid over sand
	5	15	0	12.6	-	-	92.2		1	1	0	-	
2-7-78	1-4	Drained											Section drained to bottom of gravel
2-9-78	1	Drained	D-4, 2 coverages	9.1	10.6	11.3	107.7		2	7	11	11	
	2	Drained	D-4, 2 coverages	8.6	9.2	10.3	101.6		2	2	2	6	
	3	Drained	0	8.7	9.9	17.6	102.3		2	3	2	1	AI = 10 below grid
	4	Drained	0	9.3	11.7	11.4	101.8		2	3	11	11	Two-layer grid over sand
	5	Drained	0	9.3	18.3	-	94.1		Frozen	1	0	-	
2-13-78	1	Drained	D-4, 4 coverages	7.4	9.4	10.3	-		-	-	-	-	
	2	Drained	D-4, 4 coverages	7.1	9.7	11.3	-		-	-	-	-	
	3	Drained	D-4, 4 coverages	8.2	9.7	10.6	-		-	-	-	-	
	4	Drained	D-4, 4 coverages	7.5	10.0	12.2	-		-	-	-	-	
	5	Drained	-	8.8	17.4	-	-		-	-	-	-	
2-14-78	1	Drained	D-4, 8 coverages	12.4	11.1	10.3	109.9		2	8	15+	15+	Rain blew in on Item 1
	2	Drained	plus 2 coverages	8.3	9.8	11.4	108.8		2	2	5	15+	
	3	Drained	rubber-tires plus	7.5	8.1	9.4	106.3		2	8	10	10	
	4	Drained	2 coverages vibratory roller	6.6	9.2	10.8	110.5		7	7	10	15+	
	-	-		-	-	-	-		-	-	-	-	Item 5 discarded
2-21-78	1	Drained	200 coverages	8.4	9.0	10.1	123.2	112.0	12	15+	15+	15+	
	2	Drained	C-130 traffic	10.1	9.5	9.7	119.0	109.1	2	5	5	15+	Stability of sand improved with
	3	Drained	loading	6.7	8.1	8.5	115.7	112.2	8	10	10	15+	increase in traffic coverages
	4	Drained		6.3	8.6	8.0	118.5	115.1	12	12	15+	15+	

* Airfield index is roughly equal to CBR.

Table 4

Gravel Over Insulation - Summary of CBR, Water Content, Density, and Traffic Test Results, Test Section No. 4

				Simulated C-130 Operations						Compression of Insulation, in.	
Item	Thickness over Insulation in.	Depth in.	Material	Passes	Coverages	Equivalent C-130 Operations	CBR	Water Content Percent Dry Weight	Dry Density pcf	Gage*	Actual Measurement
1	15	Surface	Crushed stone base	0	0	0	34	4.5	136.8	--	--
	15	6	Gravel subbase	0	0	0	22	7.2	130.6	--	--
	15	17	Lean clay subgrade	0	0	0	20	14.0	102.3	--	--
1	15	Surface	Crushed stone base	480	280	1134	85	3.4	147.0	0.004	0.00
1	9(9)**	Surface***	Gravel subbase	68	52	210	49	6.6	135.4	0.25	0.95
2	17.5	Surface	Crushed stone base	0	0	0	35	4.4	136.8	--	--
	17.5	6	Gravel subbase	0	0	0	24	7.2	130.0	--	--
	17.5	19.5	Lean clay subgrade	0	0	0	22	12.5	103.7	--	--
2	17.5	Surface	Crushed stone base	480	280	1134	75	4.3	143.3	0.003	--
2	11.5 (10.2)**	Surface***	Gravel subbase	68	52	210	59	6.4	136.6	0.125	0.25
3	20.0	Surface	Crushed stone base	0	0	0	35	4.5	137.2	--	--
	20.0	6	Gravel subbase	0	0	0	22	7.5	131.1	--	--
	20.0	22	Lean clay subgrade	0	0	0	22	15.0	101.9	--	--
3	20.0	Surface	Crushed stone base	480	280	1134	80	3.7	144.6	0.003	--
3	14.0 (11.1)**	Surface***	Gravel subbase	68	52	210	53	6.0	135.7	0.06	0.25

*Indicated compression represents averages from two gages.
**Figures in parentheses indicate average thickness of gravel over insulation at the end of traffic.
***Additional traffic applied after removing top 6 in. of crushed stone base.

Table 5

Results from Unconfined Compression Test with Single Loading

Sample No.	Sample Height in.	Diameter in.	Stress at 5% Strain psi	Elastic Modulus psi
A-1	2.062	3.034	69	2500
A-2	2.073	3.061	67	2500
A-3	2.044	3.051	63	2400
B-1	1.575	3.061	72	2400
B-2	1.602	3.052	58	2200
B-3	1.519	3.054	70	2400
C-1	6.264	3.056	62	2100

Table 6

Results from Unconfined Compression Test with Repeated Loadings

Sample No.	Sample Height in.	Applied Pressure psi	Stress Repetition	Resilient Strain in./in.	Permanent Strain in./in.	Resilient Modulus psi
1	2.093	40	1	0.016	0.003	3750
			10	0.016	0.006	3750
			100	0.016	0.009	3750
			1000	0.016	0.014	3750
2	2.059	50	1	0.014	0.003	3571
			10	0.014	0.004	3571
			100	0.014	0.007	3571
			1000	0.014	0.011	3571
3	2.119	60	1	0.0010	0.0014	4000
			10	0.0010	0.0019	4000
			100	0.0010	0.0024	4000
			1000	0.0010	0.0029	4000

Table 7

Sand-Grid Confinement Study
Summary of CBR, Water Content, and Density Data,
Test Section No. 5

After Traffic						
Item	Gride Size in.	Material	Depth in.	CBR	Water Content Percent Dry Weight	Dry Density pcf
1	6 by 6 by 6	Sand	Surface	23	8.2	112.3
		Sand	6	36	7.1	118.6
		Sand	12	35	7.0	119.8
		Subgrade	18	17	14.8	98.9
2	8 by 8 by 6	Sand	Surface	21	5.6	109.2
		Sand	6	42	5.6	117.4
		Sand	12	36	5.3	115.8
		Subgrade	18	22	12.6	102.3
3	12 by 12 by 12	Sand	Surface	20	9.0	113.9
		Sand	6	35	6.3	116.6
		Sand	12	37	6.1	116.9
		Subgrade	18	25	13.0	100.1
4	No grid	Sand	Surface	15	8.9	111.3
		Sand	6	22	6.5	113.3
		Sand	12	33	4.9	113.2
		Subgrade	18	18	13.5	100.0

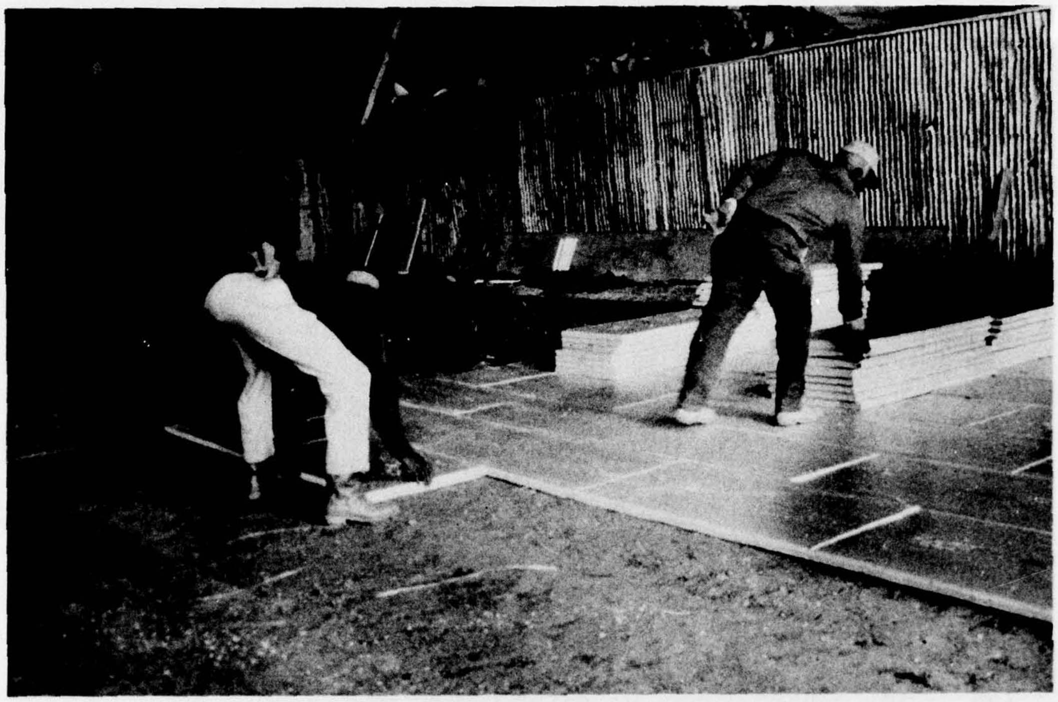


Photo 1. Placing bottom layer of Styrofoam insulation

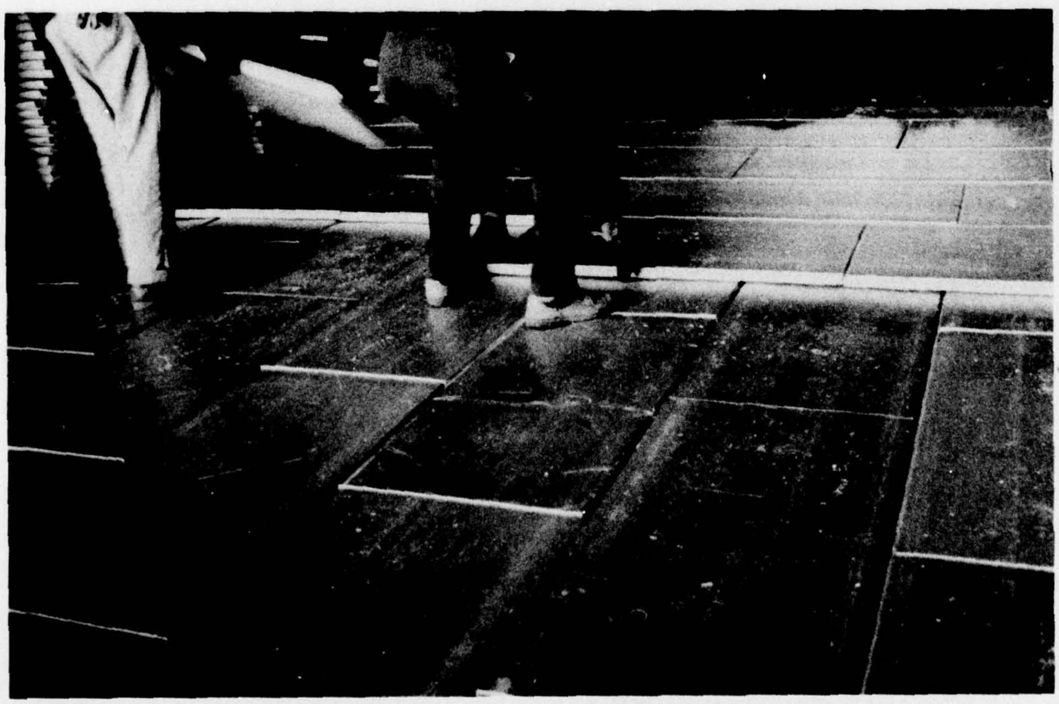


Photo 2. Placing top layer of Styrofoam insulation

Photo 3. Gravel base over insulation

Photo 4. Placing XM19 landing mat over insulation

Photo 5. General view of XM19 landing mat, Test Section No. 1, item 1, prior to traffic

Photo 6. General view of XM19 landing mat, Test Section No. 1, item 1, after traffic

Photo 7. General view of base course, Test Section No. 1, item 2, after traffic

Photo 8. General view of insulation in Test Section No. 1, item 1, after traffic

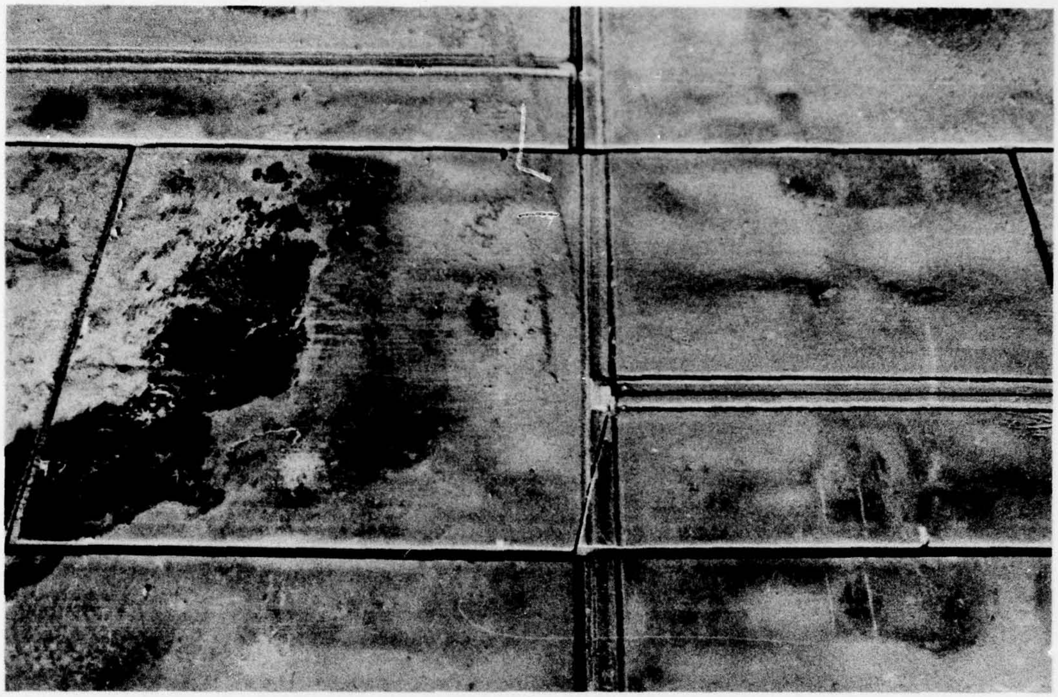


Photo 9. Closeup view of insulation in Test Section No. 1, item 1, after traffic

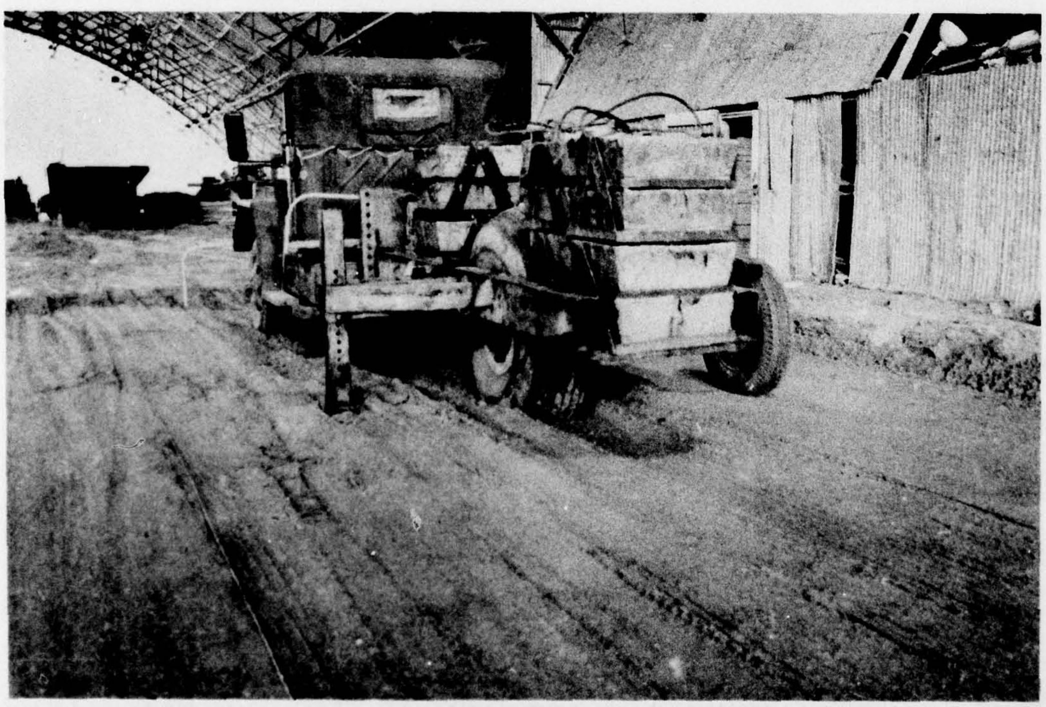


Photo 10. Test Section No. 1, item 2, with 10 in. of gravel over insulation

Photo 11. Test Section No. 2 trench lined with waterproof membrane

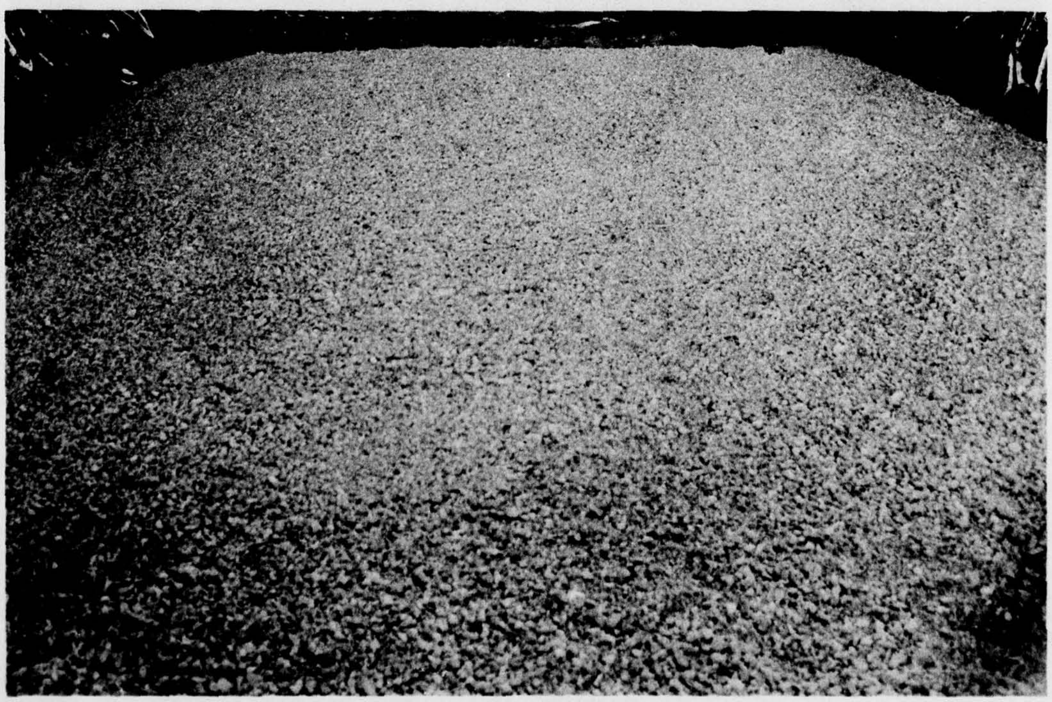


Photo 12. General view of finished gravel blanket

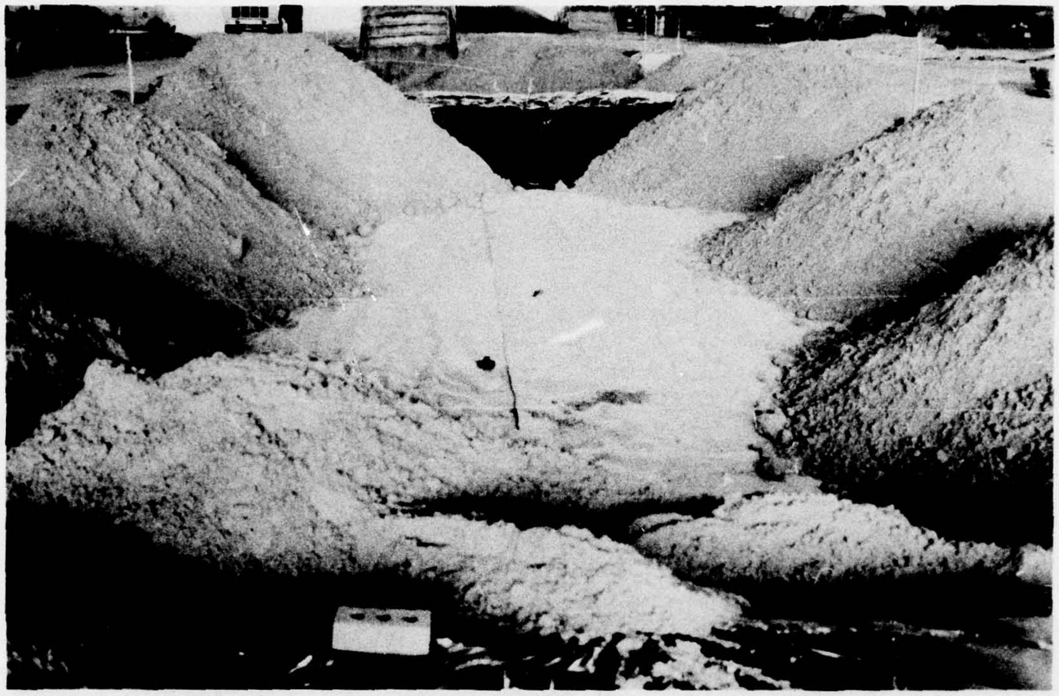


Photo 13. Sand end dumped on top of filter cloth

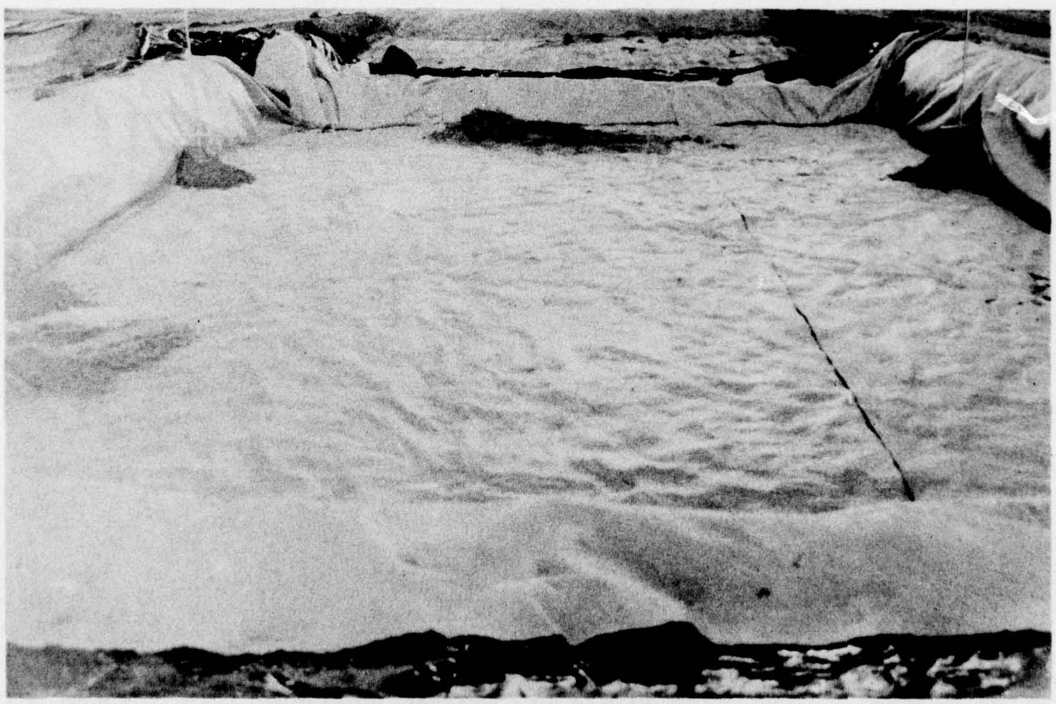


Photo 14. Filter cloth installed over gravel and sides of trench in Test Section No. 2, item 3

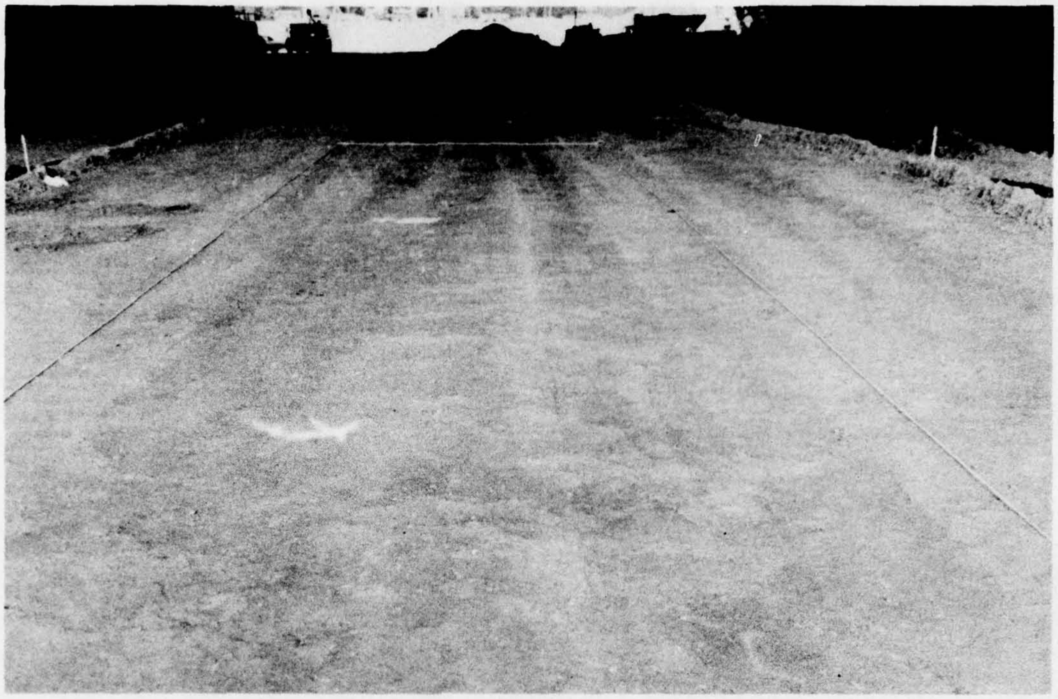


Photo 15. General view of completed Test Section No. 2 prior to traffic

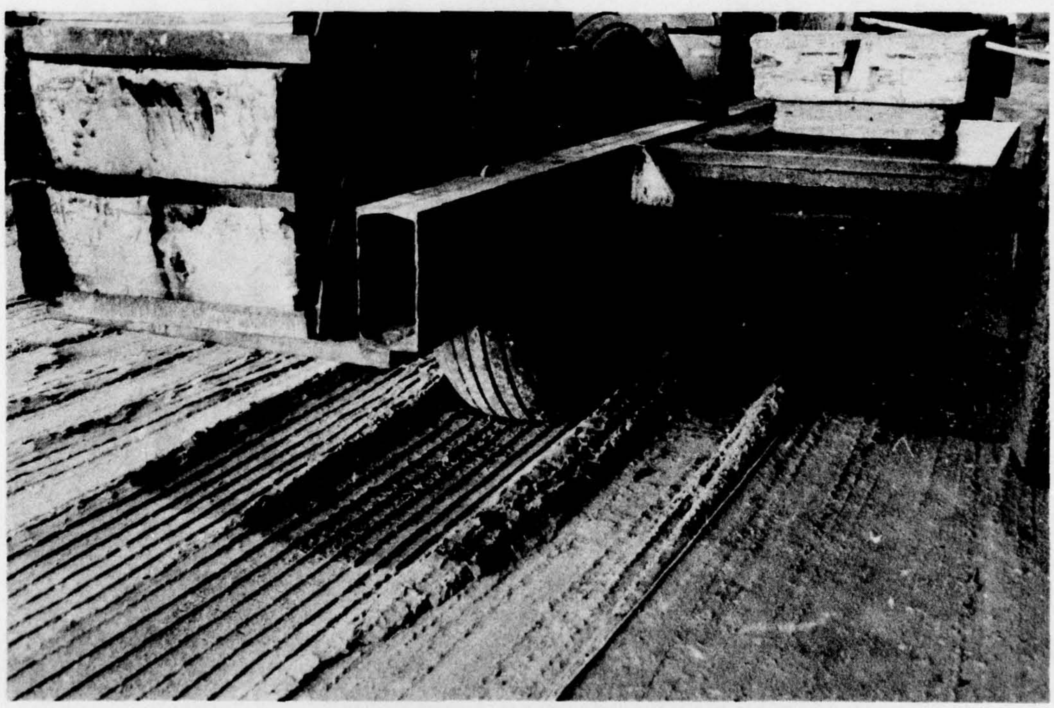


Photo 16. Test Section No. 2 with test cart immobilized after 22 passes in item 2

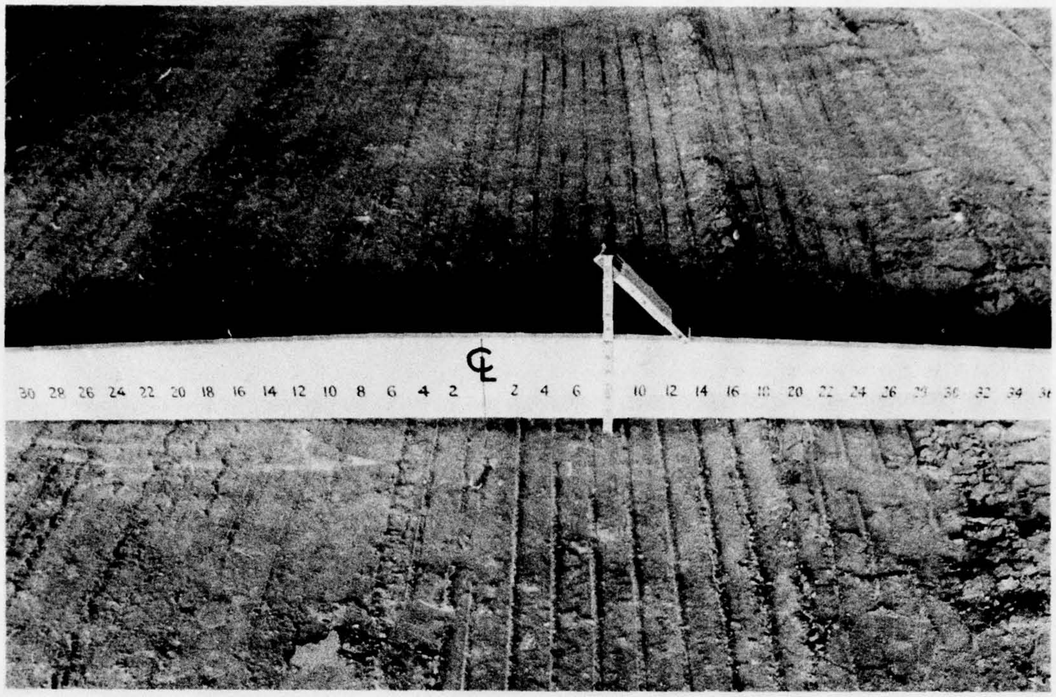


Photo 17. General view of Test Section No. 2, item 1, after 714 passes, 35-kip single-wheel load

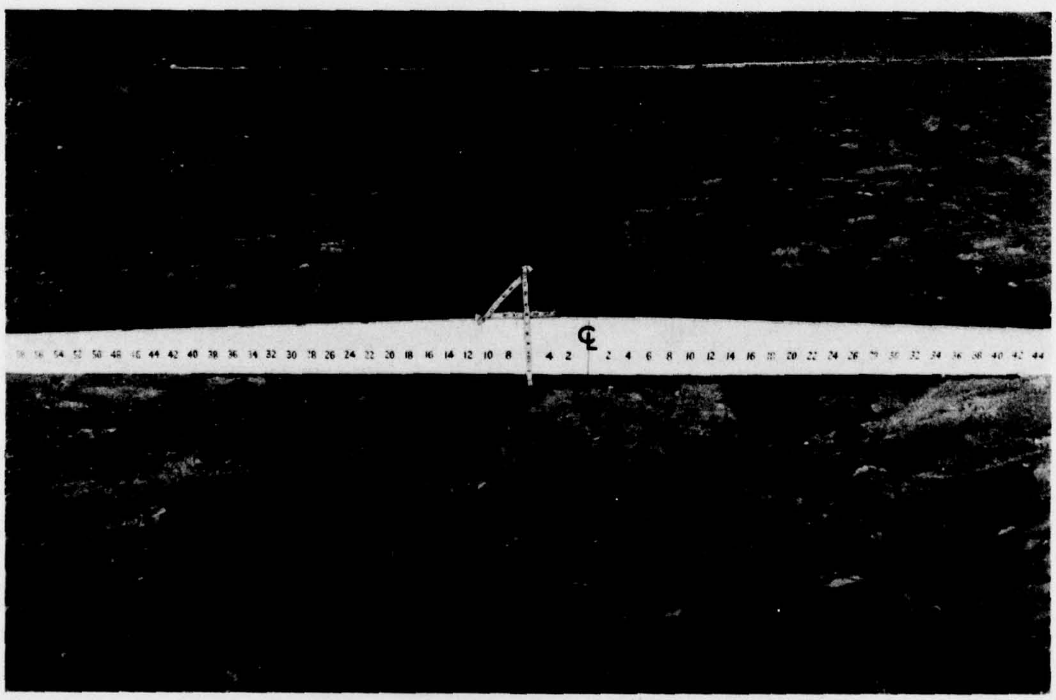


Photo 18. General view of Test Section No. 2, item 1, at end of traffic

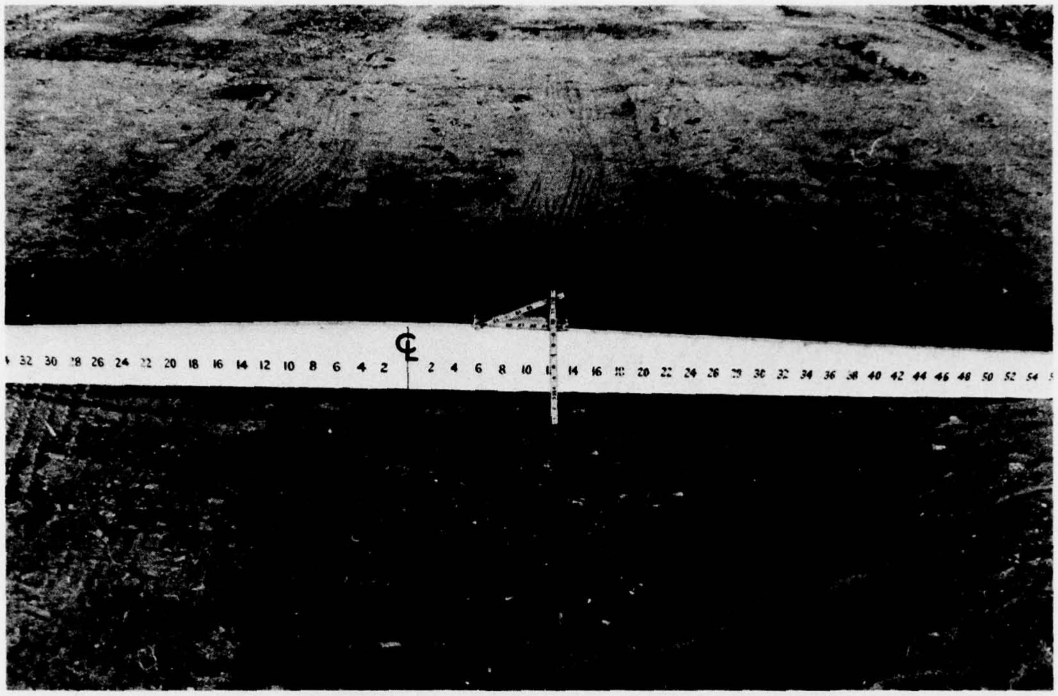


Photo 19. General view of Test Section No. 2, item 2, at end of traffic

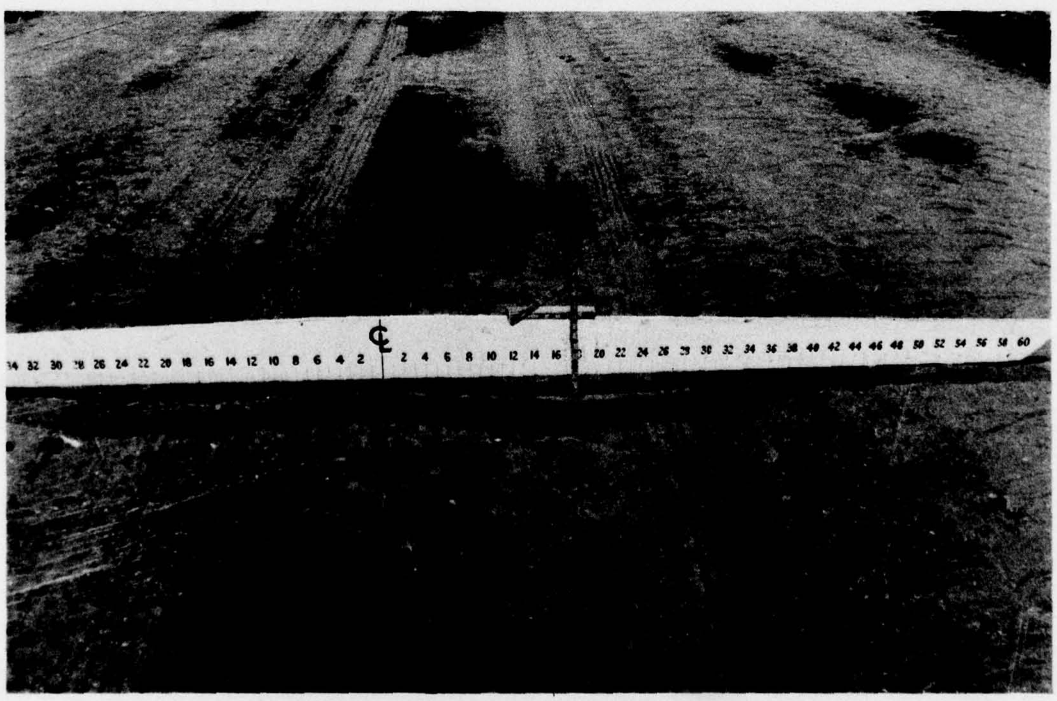


Photo 20. General view of Test Section No. 2, item 3, at end of traffic

Photo 21. Membrane-lined Test Section No. 3 trench

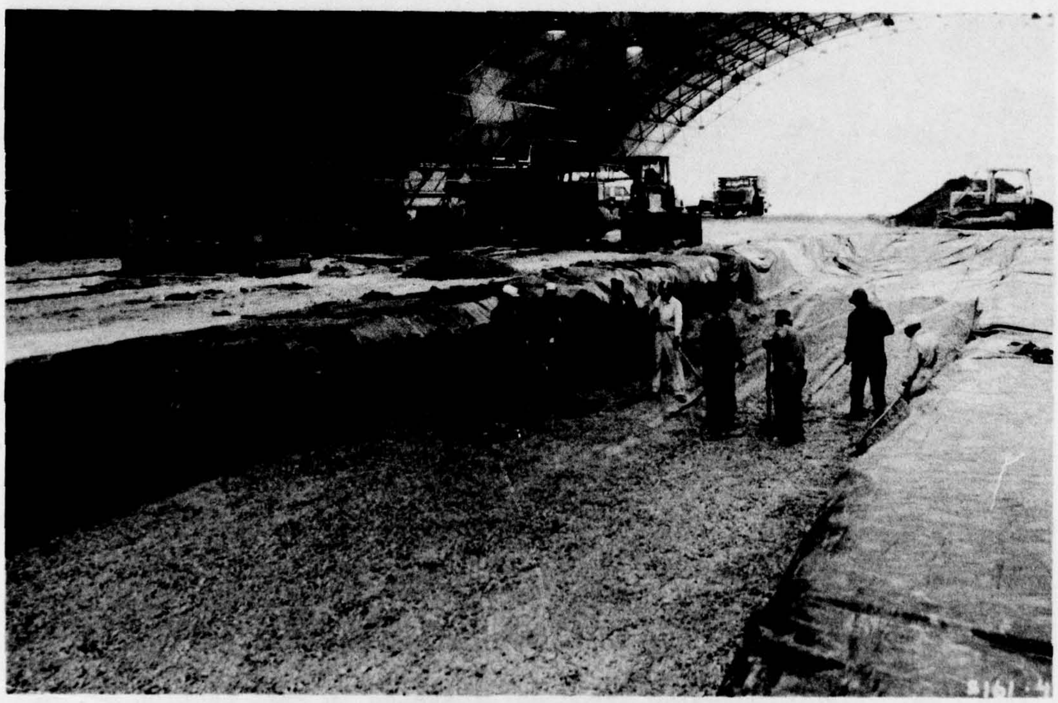


Photo 22. Hand leveling washed gravel

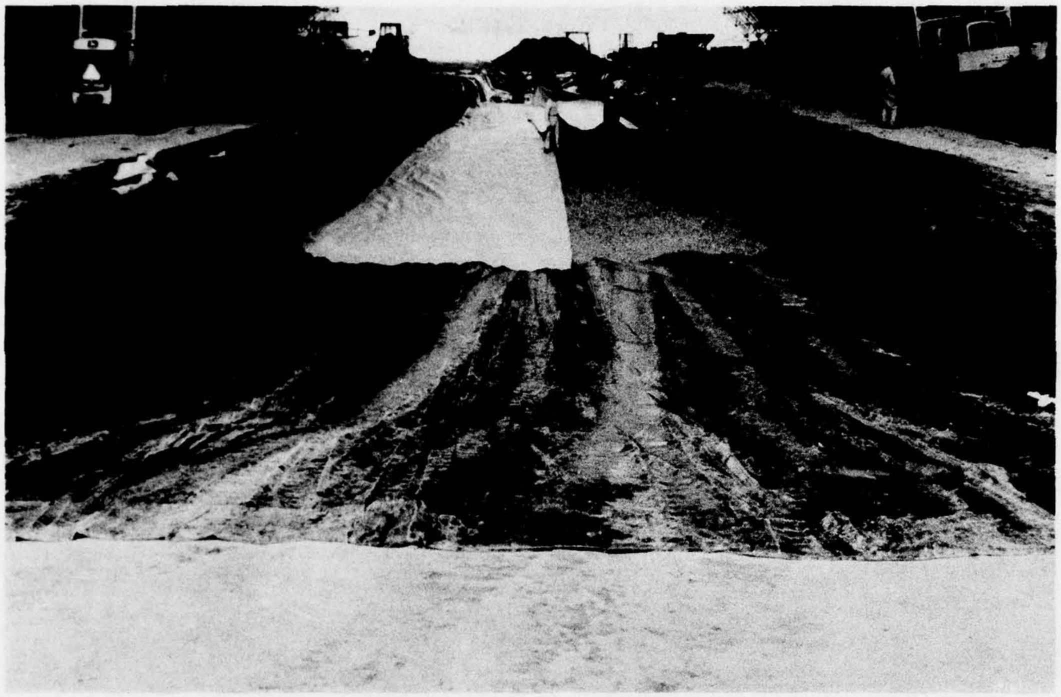


Photo 23. Placing filter cloth over gravel

Photo 24. Eight-foot-wide trenches excavated in Test Section No. 3, item 4, to be backfilled with loose sand

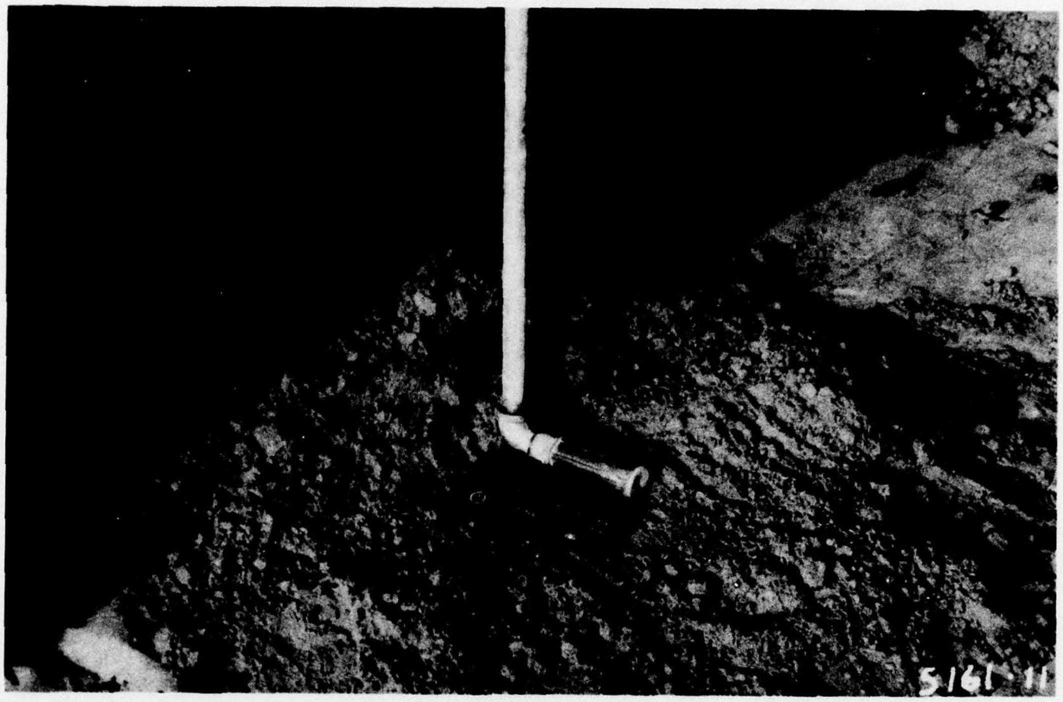


Photo 25. Typical view of piezometer installation at bottom of sand fill

Photo 26. End dumping sand into Test Section No. 3 trench

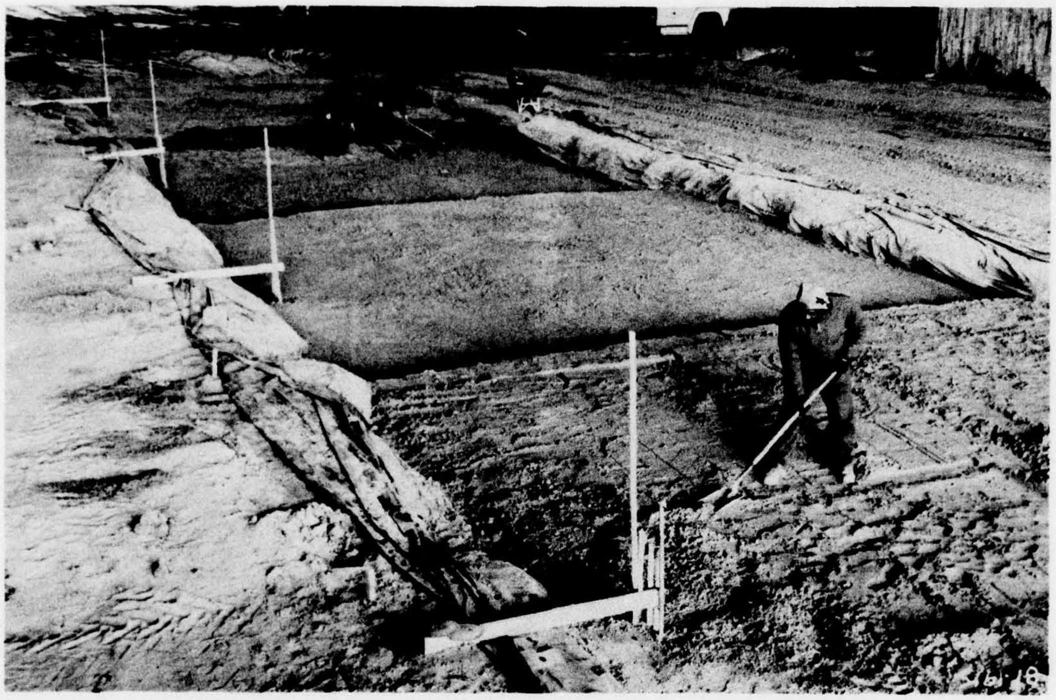


Photo 27. Hand leveling of sand surface prior to placing grids

Photo 28. Paper grid pallets, as received

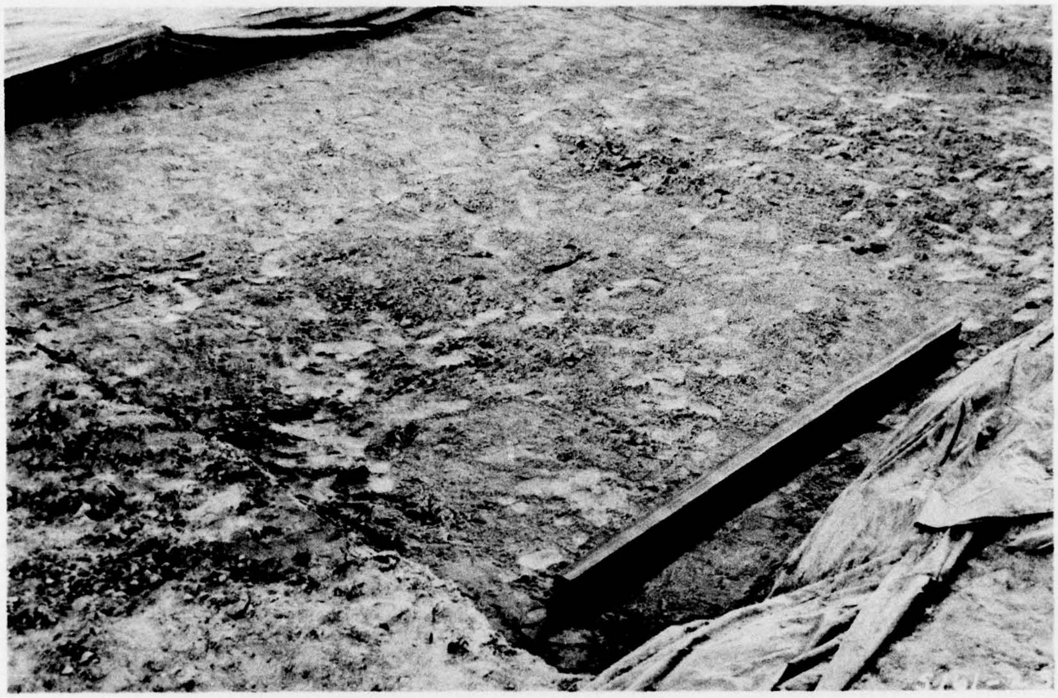


Photo 29. One piece 3- by 6- by 126-in. grid prior to expansion

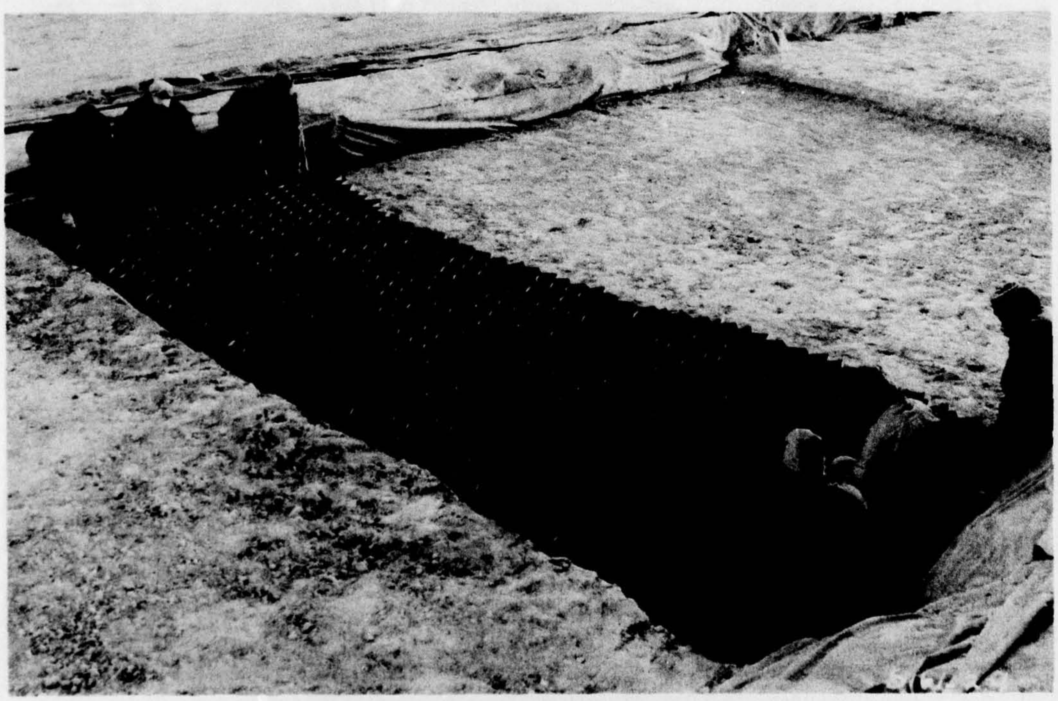


Photo 30. Grid expanded to 8- by 14-ft panel

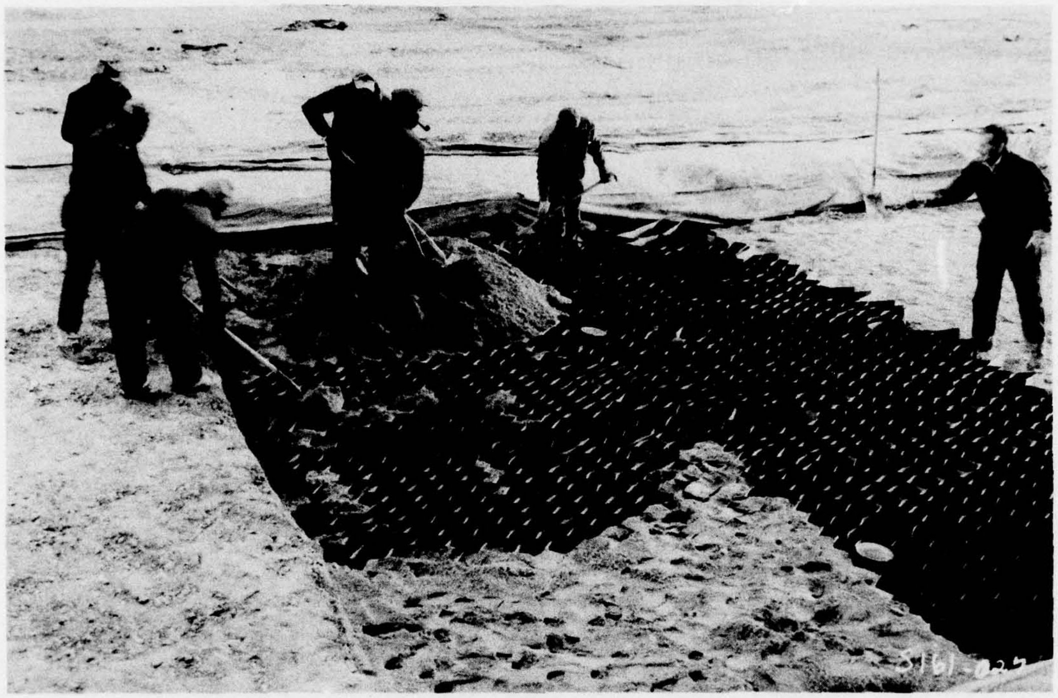


Photo 31. Filling grids with hand shovels

Photo 32. Tearing of paper and glued joints

Photo 33. Placing insulation over membrane

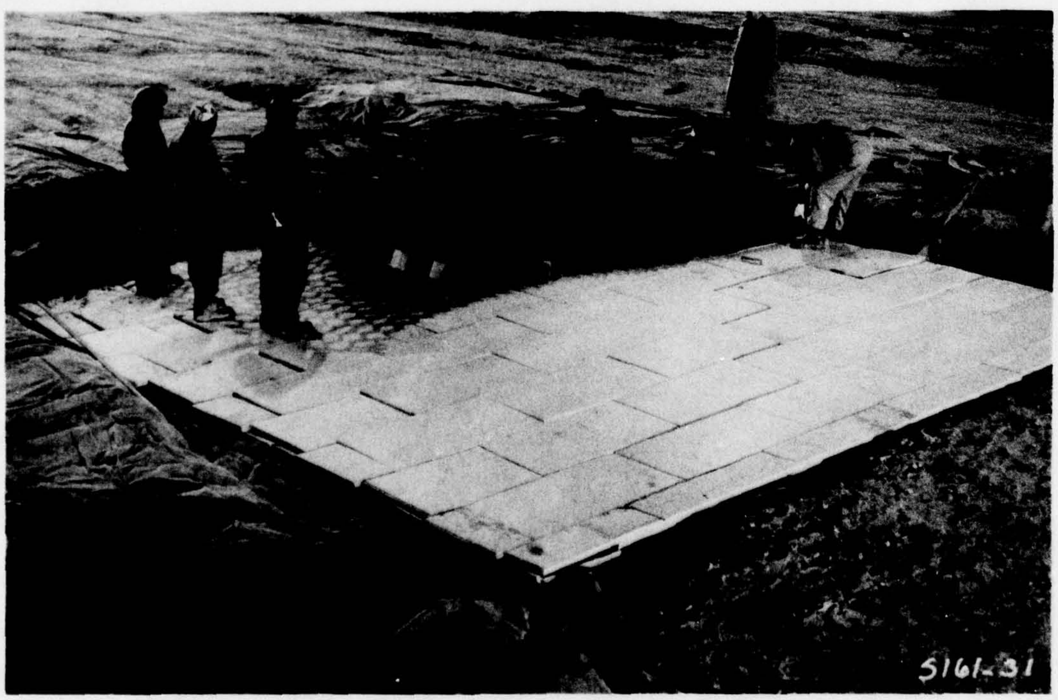


Photo 34. Placing paper grid over Styrofoam insulation

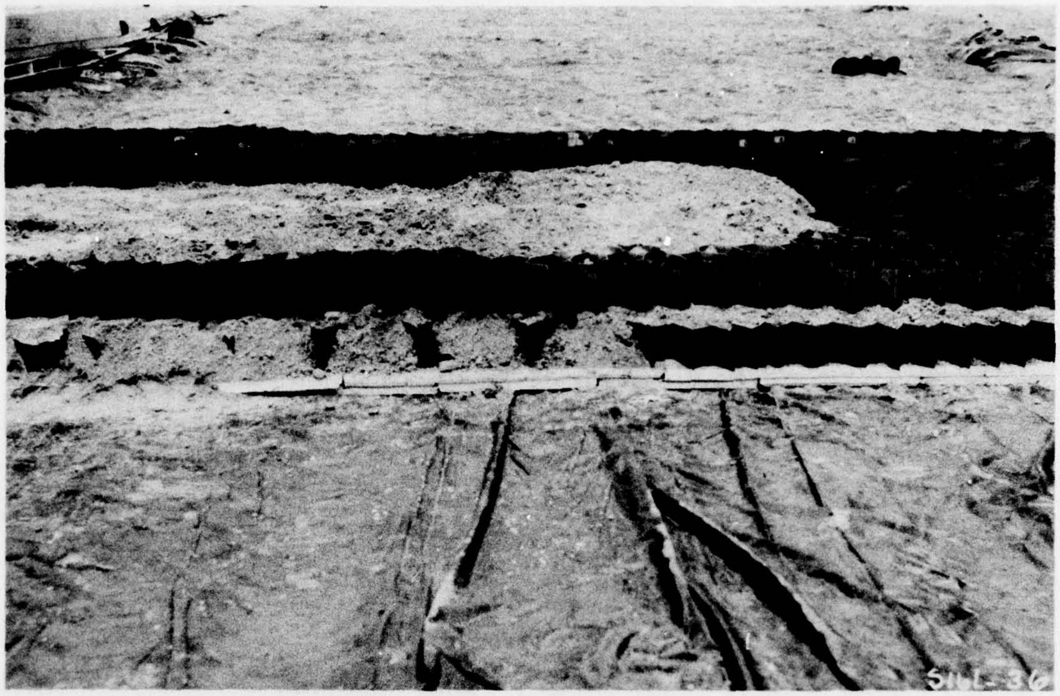


Photo 35. End view of top layer of grid over insulation

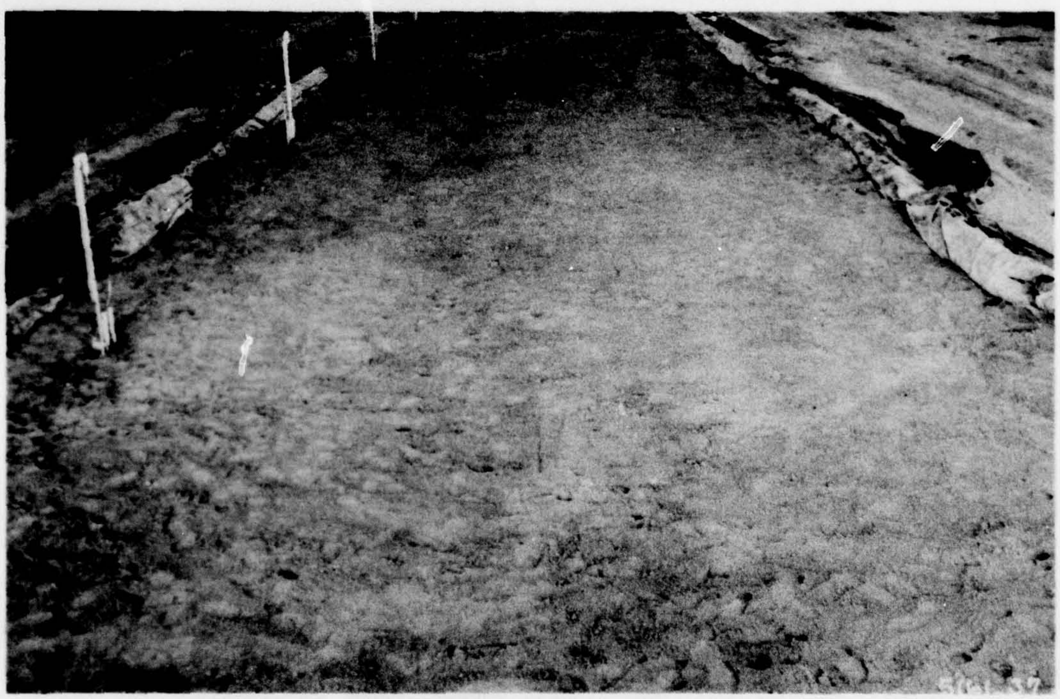


Photo 36. General view of Test Section No. 3 after installation of grids

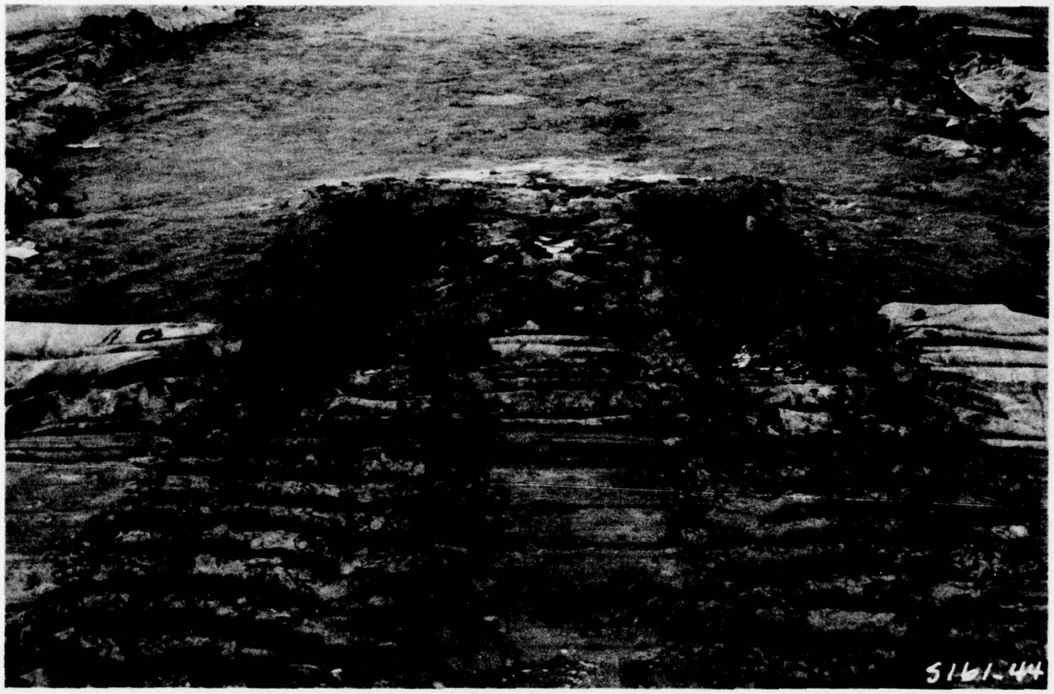


Photo 37. Closeup showing rutting and damaged grid from D-4 tractor

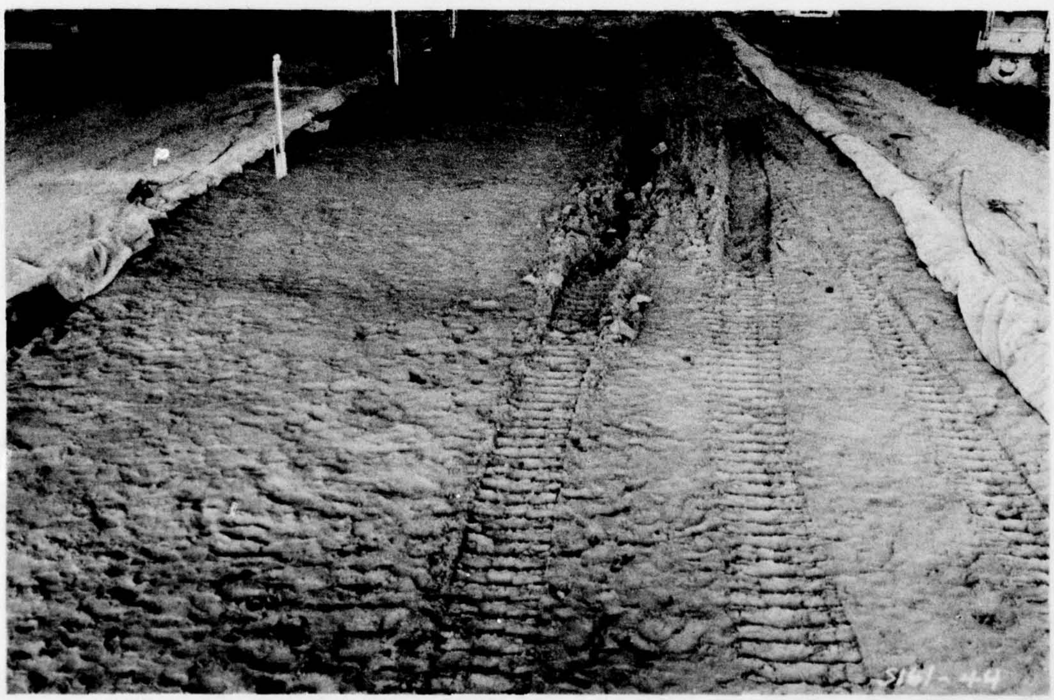


Photo 38. Two passes of D-4 tractor, Test Section No. 3, items 1 and 2, water level 23 in. below surface

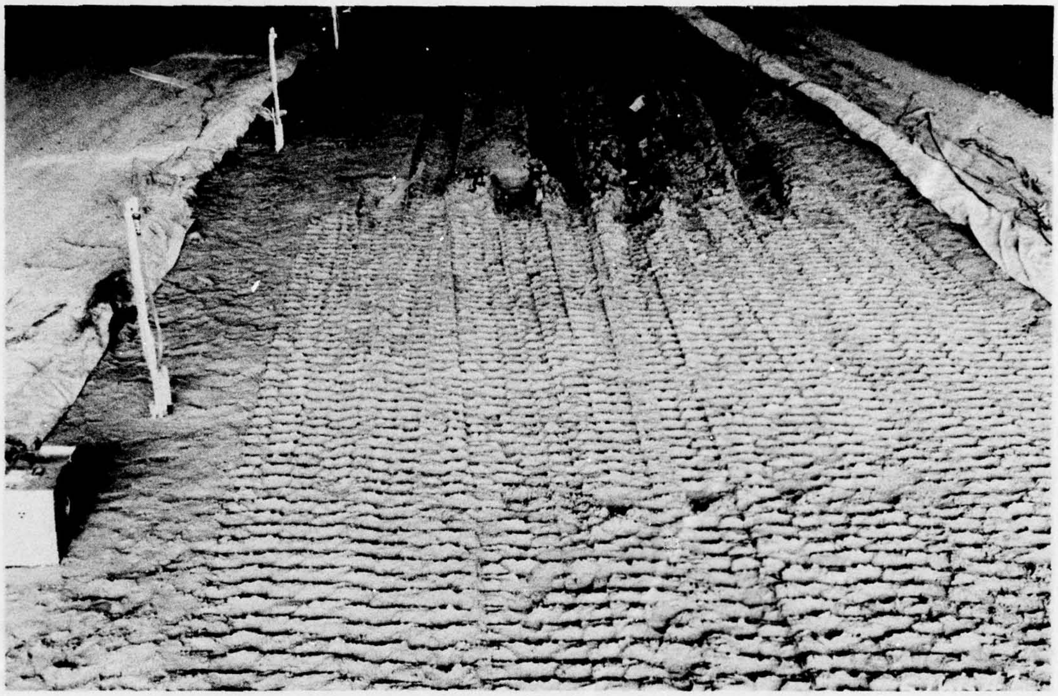


Photo 39. Two coverages of D-4 over item 1 (foreground) and two passes of D4 over item 2 (background), Test Section No. 3

Photo 40. Closeup of damaged grid and water in ruts of Test Section No. 3, item 2

Photo 41. Compaction with D-4 tractor

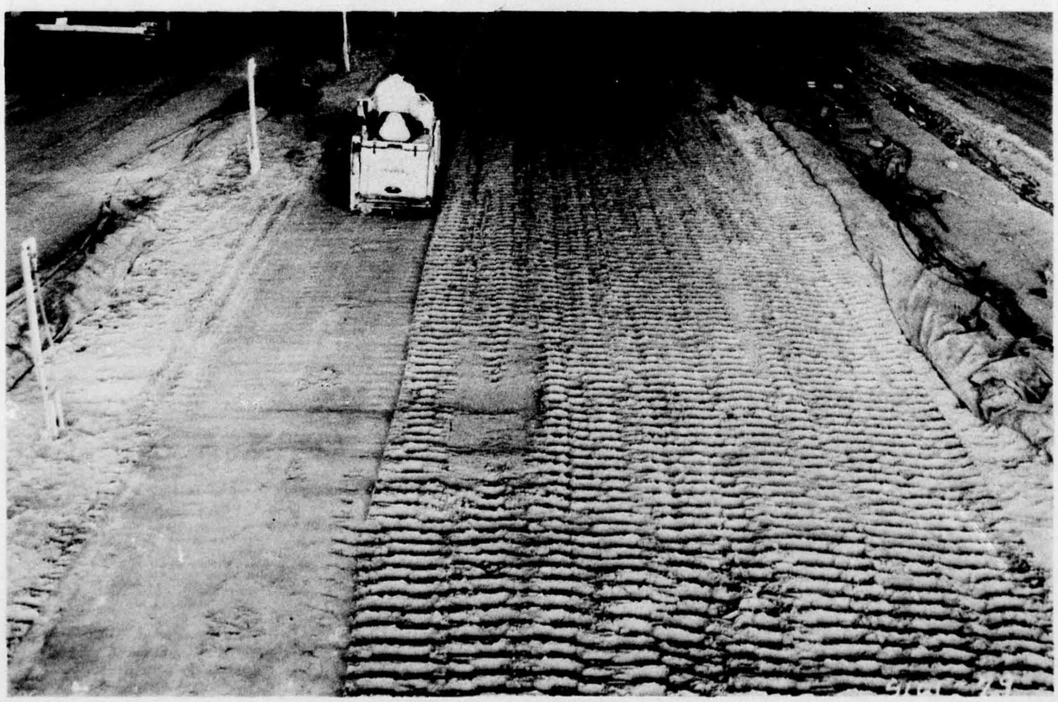


Photo 42. Compaction with vibratory roller

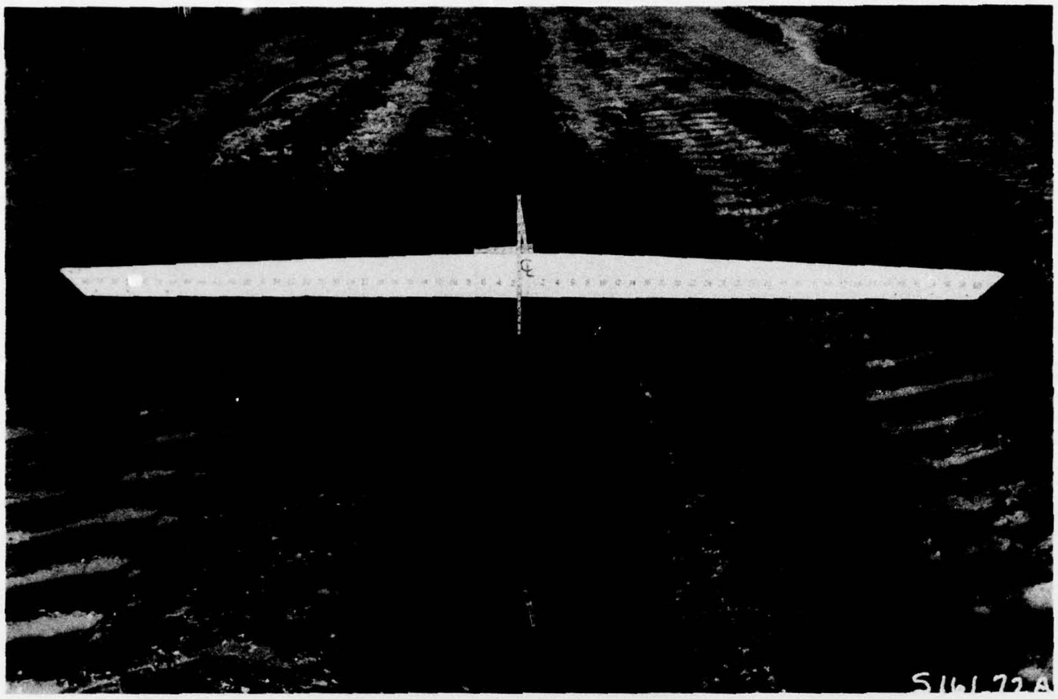


Photo 43. Rutting by two passes of load wheel

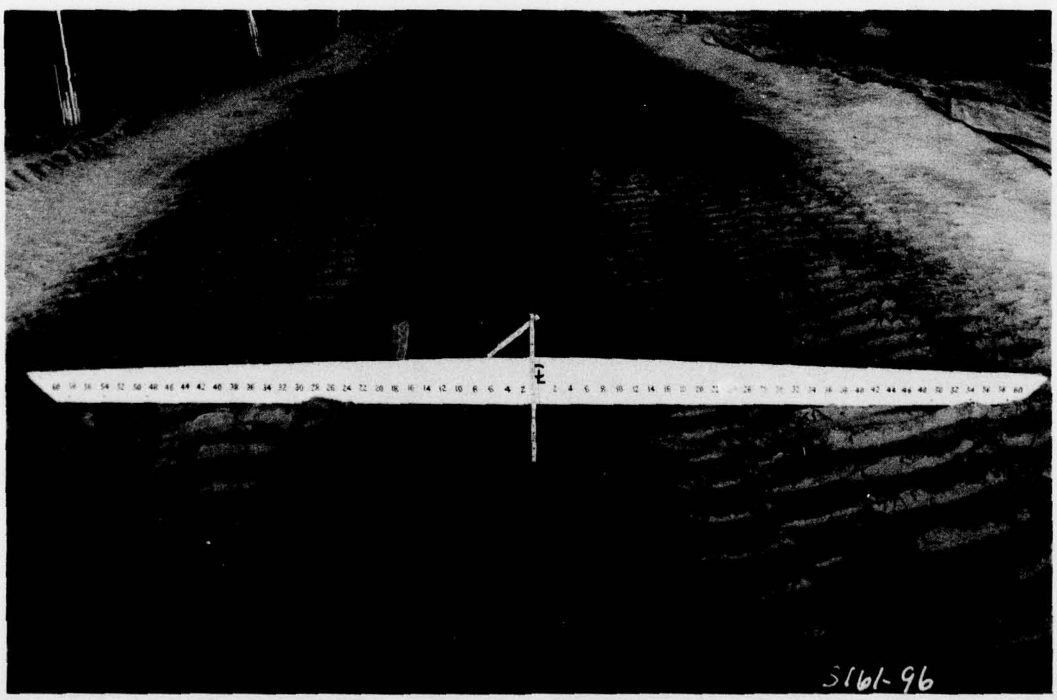


Photo 44. Test Section No. 3, item 1, after 100 coverages of C-130 loading

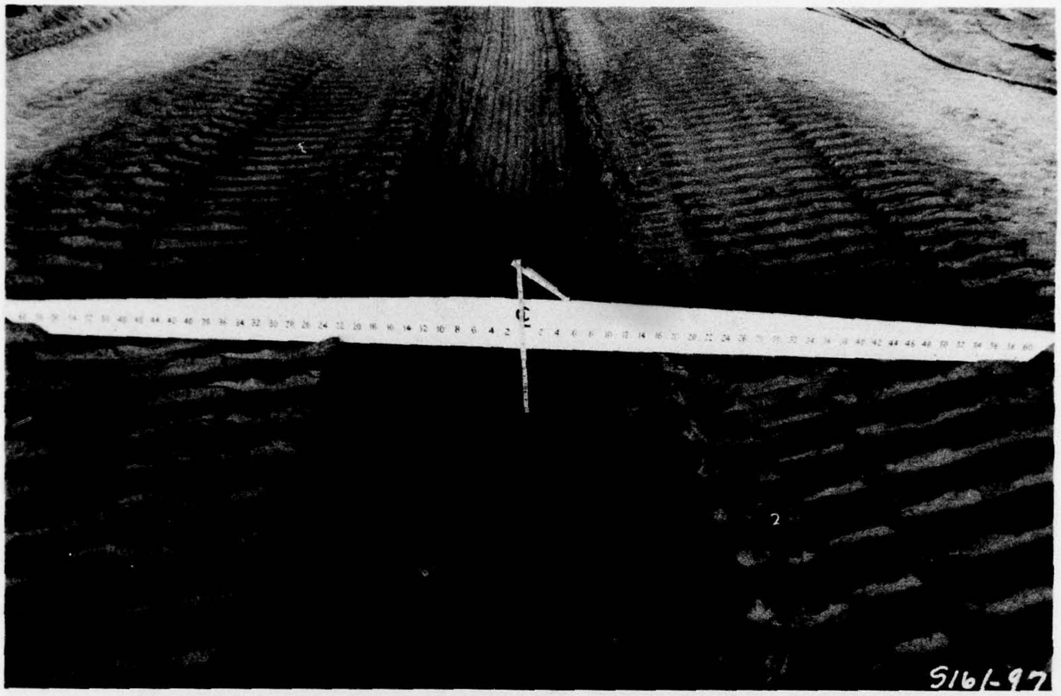


Photo 45. Test Section No. 3, item 2, after 100 coverages of C-130 loading

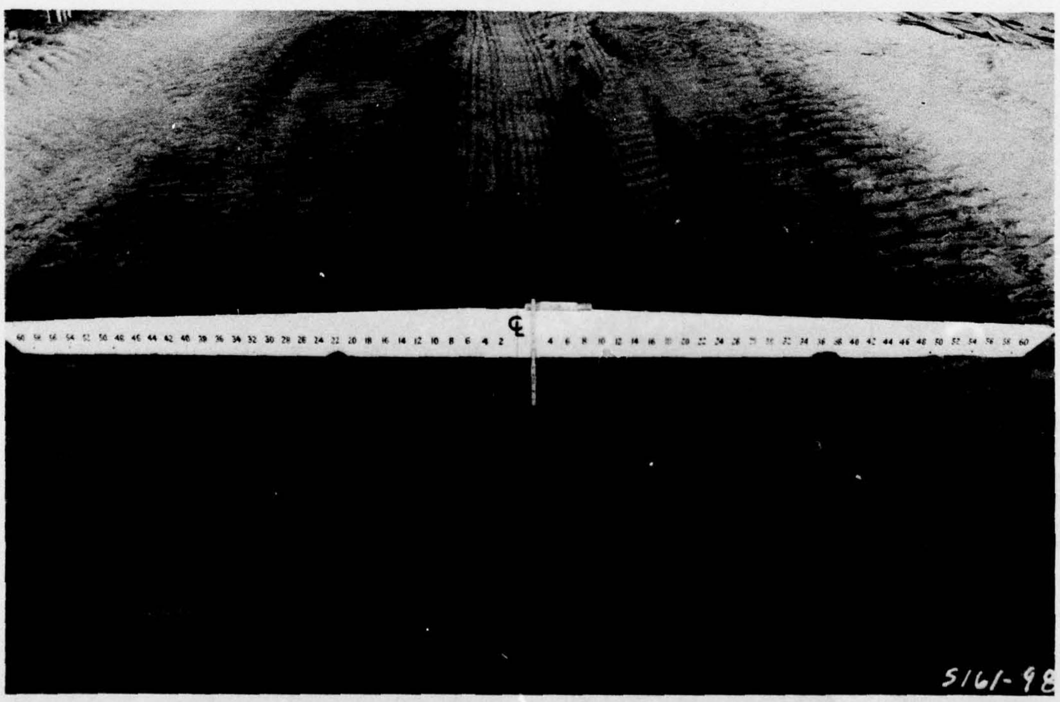


Photo 46. Test Section No. 3, item 3, after 100 coverages of C-130 loading

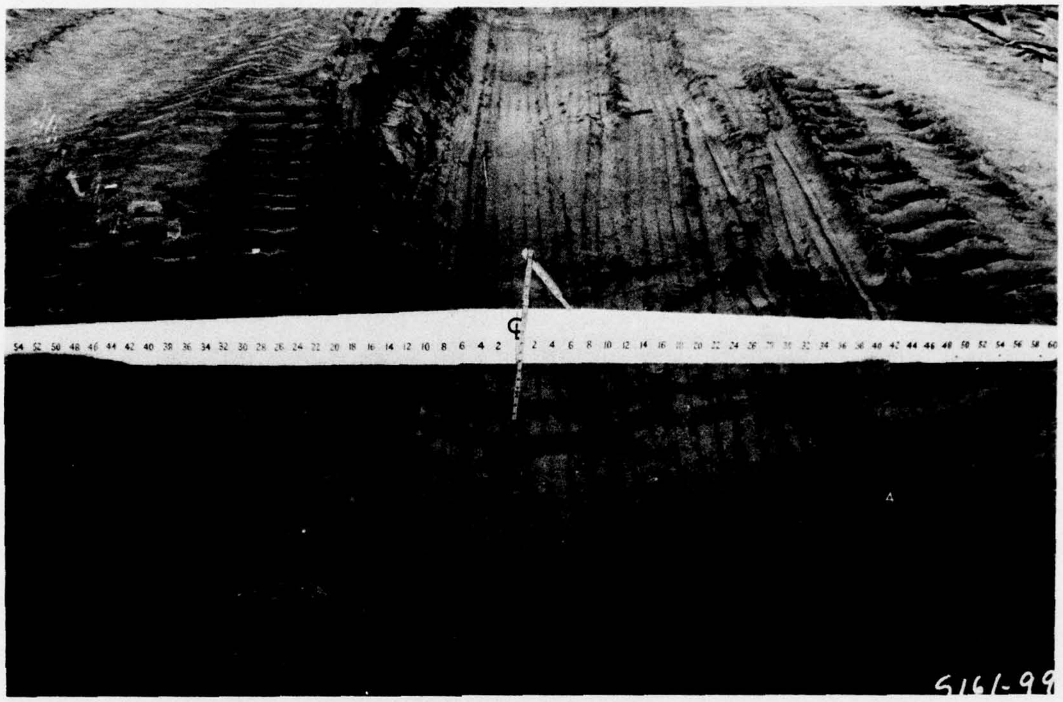


Photo 47. Test Section No. 3, item 4, after 100 coverages of C-130 loading over stabilized base

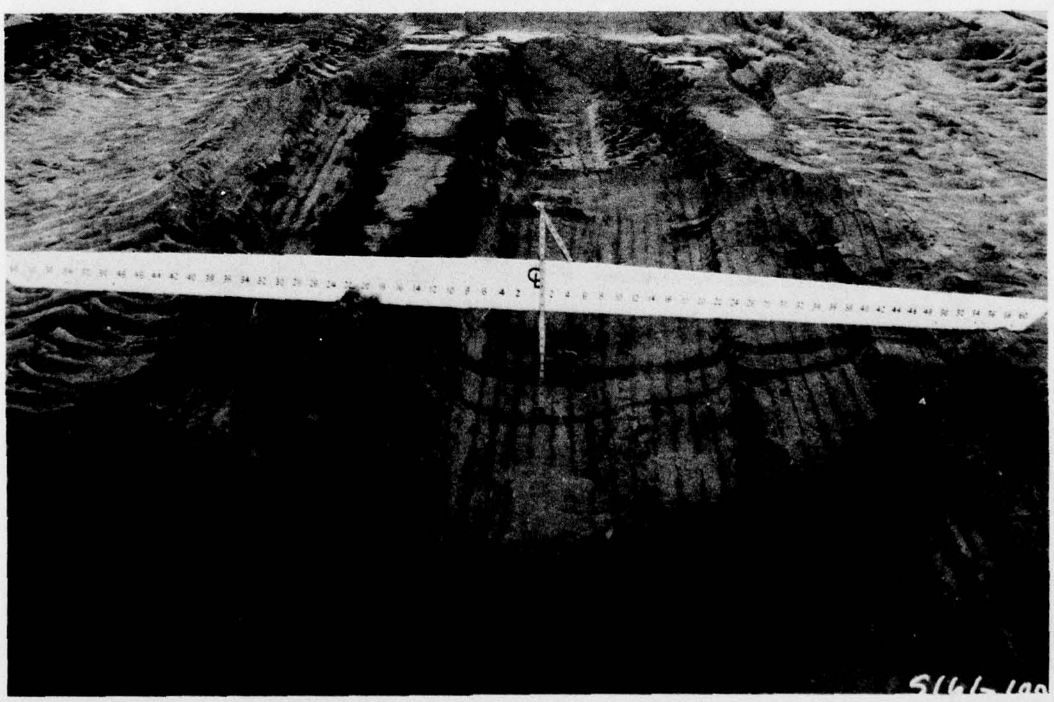


Photo 48. Test Section No. 3, item 4, after 100 coverages of C-130 loading over loose sand

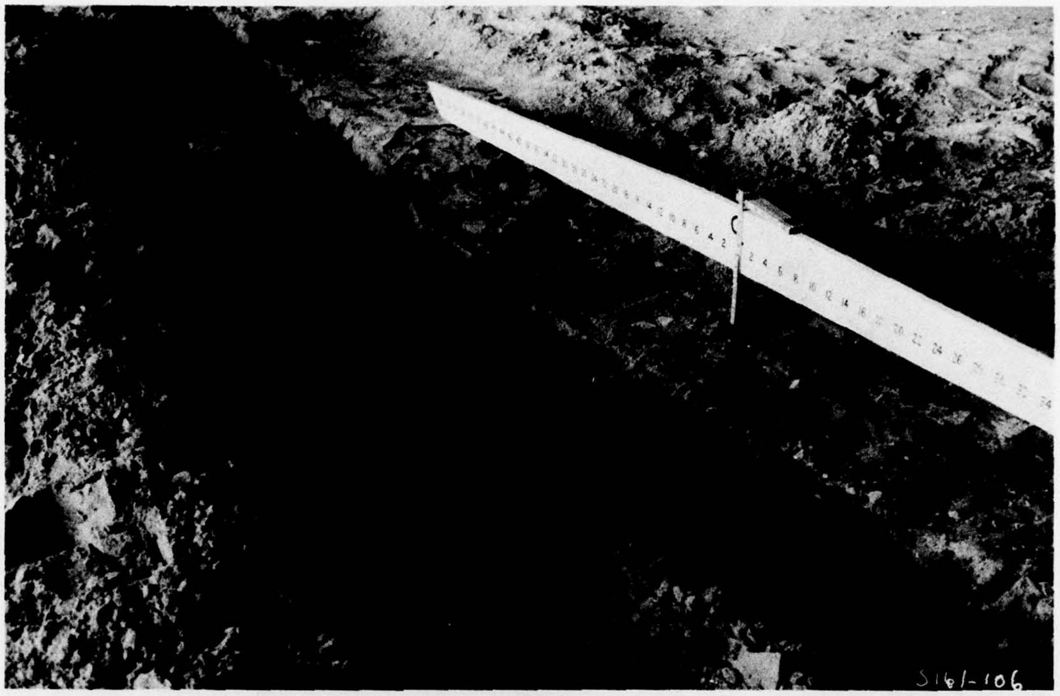


Photo 49. Test Section No. 3, item 1, trench after 200 coverages

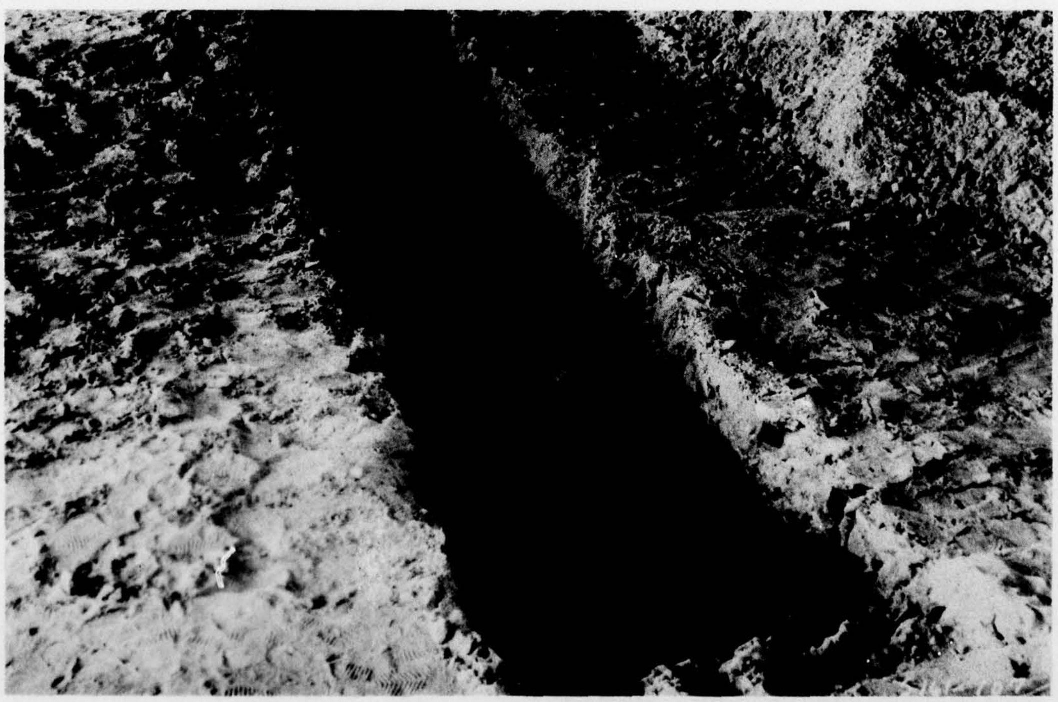


Photo 50. Test Section No. 3, item 2, trench after 200 coverages

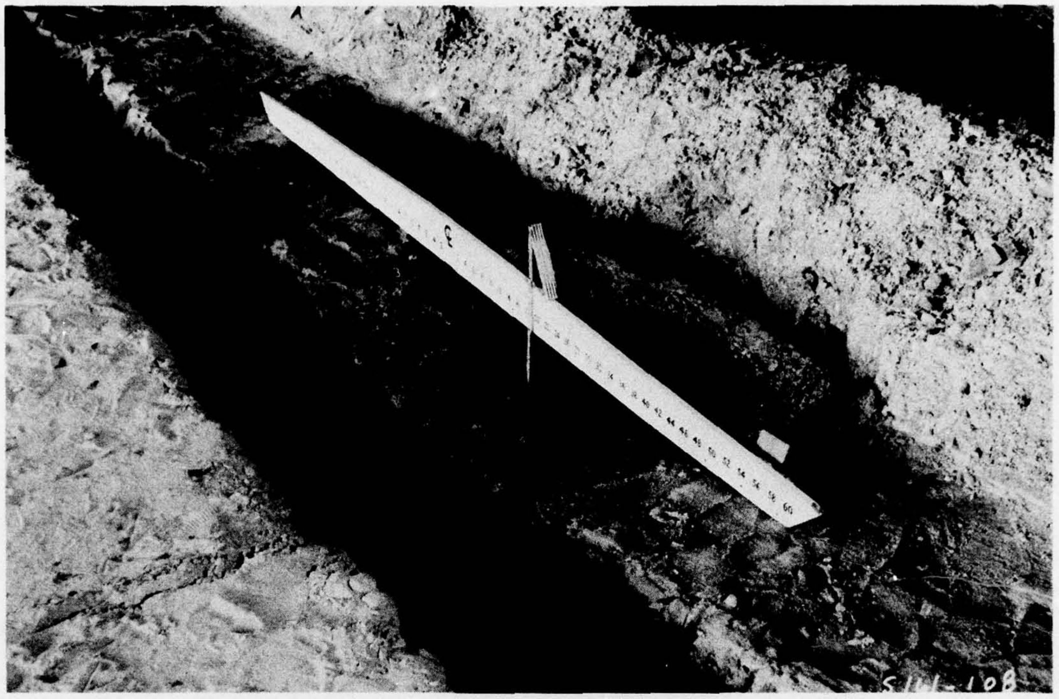


Photo 51. Test Section No. 3, item 3, trench after 200 coverages

Photo 52. Test Section No. 3, item 4, trench after 200 coverages

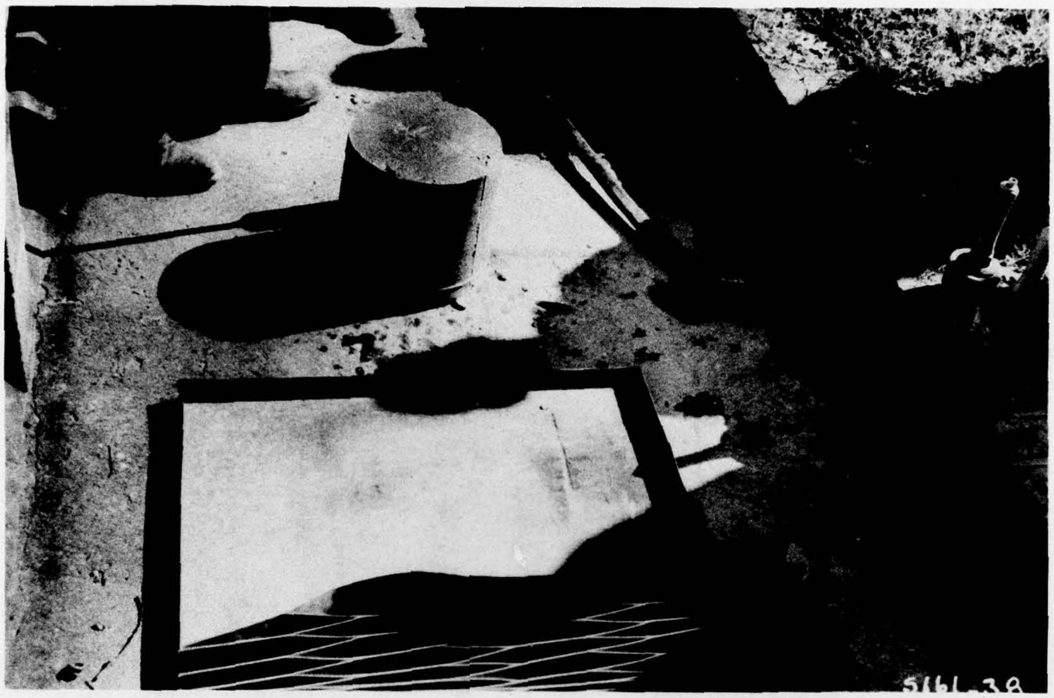


Photo 53. Sand frozen at -40°F

Photo 54. Breaking up frozen sand with ax

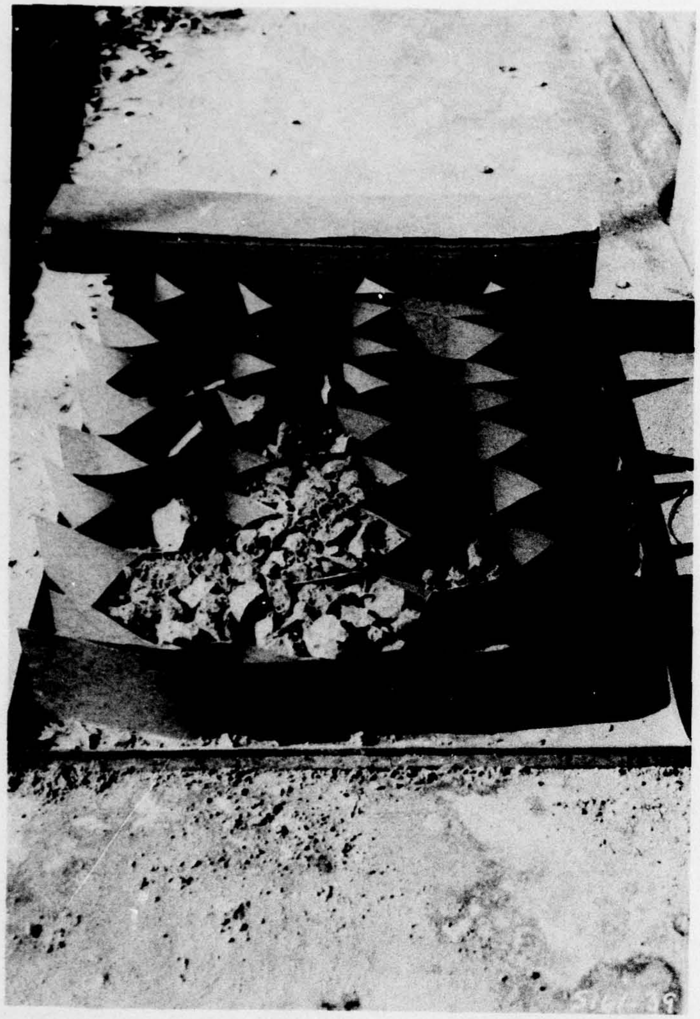


Photo 55. Placing crushed frozen sand in grid

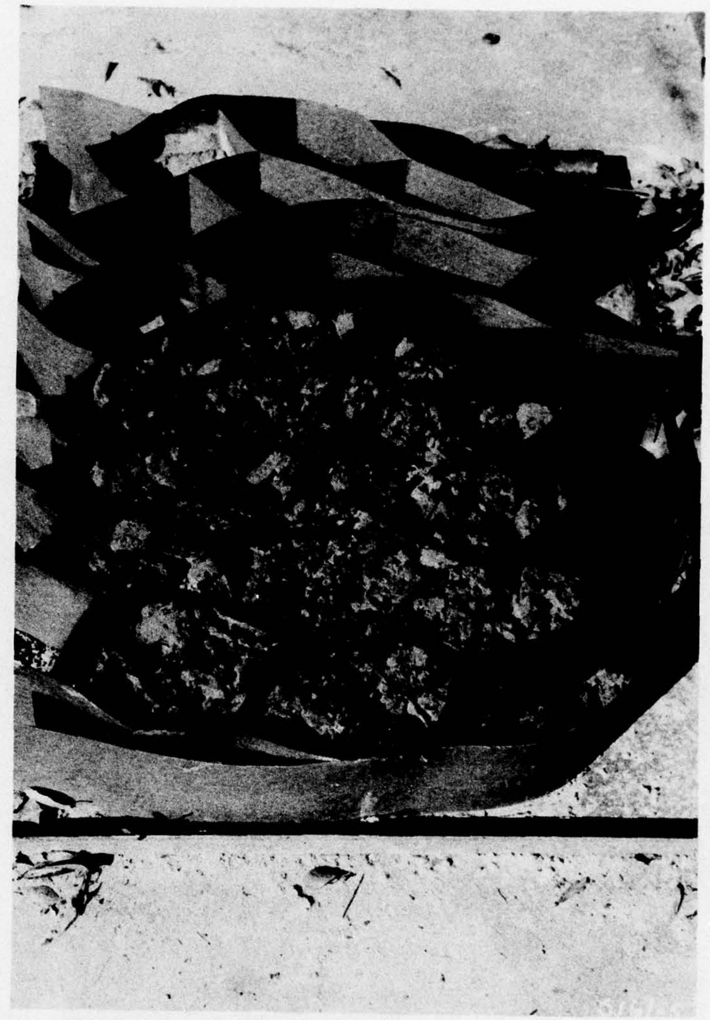


Photo 56. Crushed frozen sand after thaw

Photo 57. General view of prepared subgrade

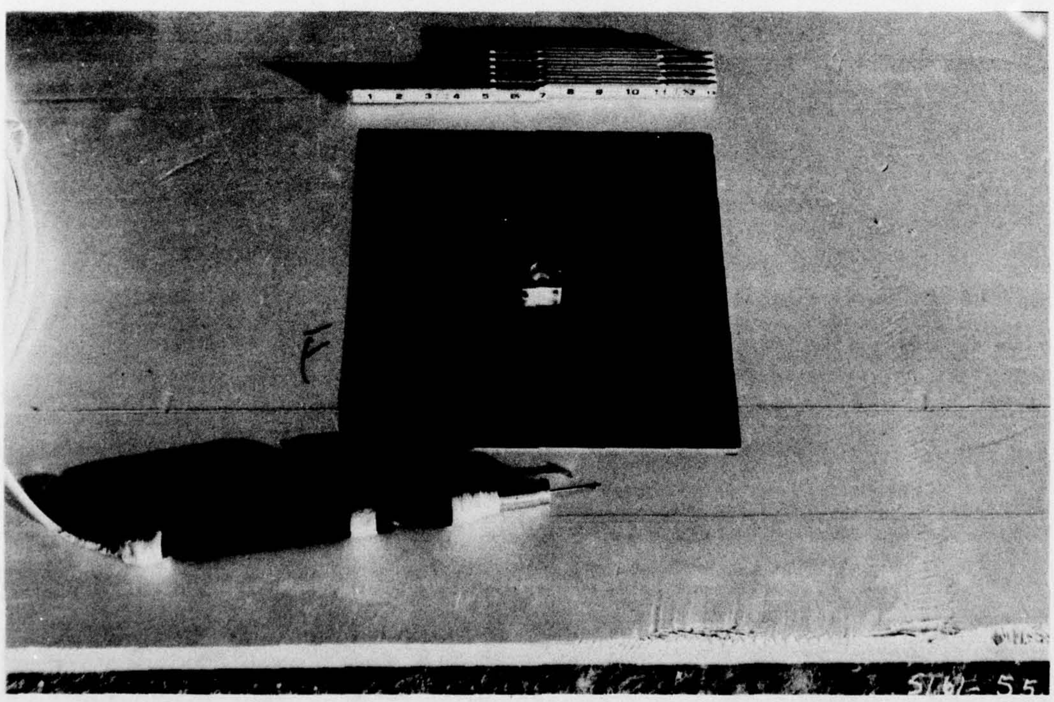


Photo 58. Thin aluminum plate glued to bottom of foam for gage insulation

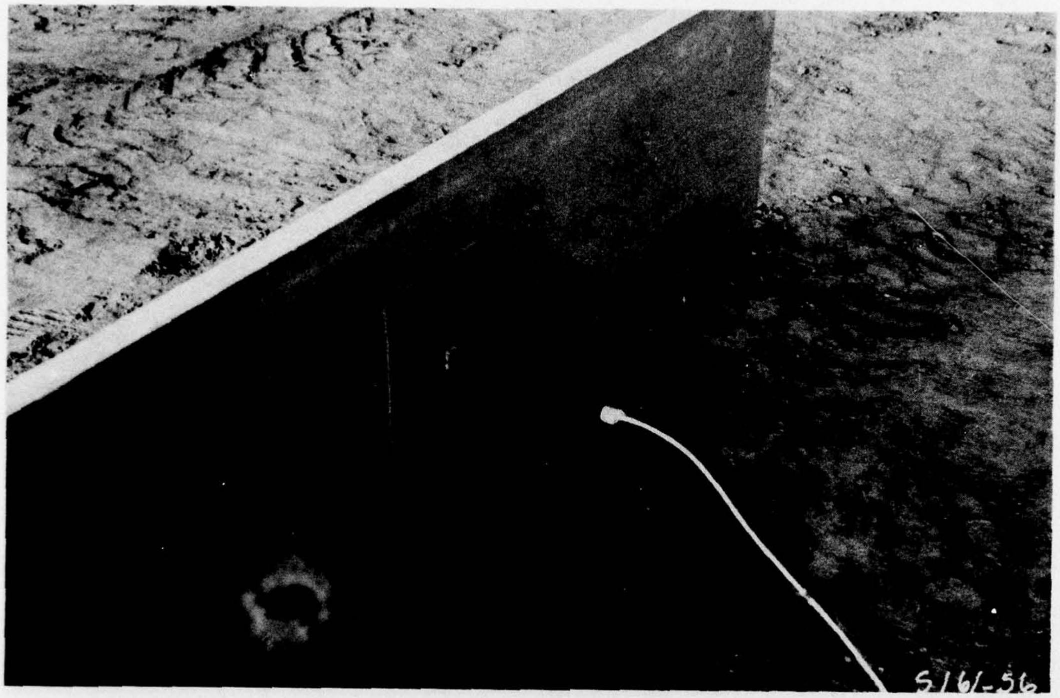


Photo 59. Three-inch-diameter hole in subgrade to receive DCDT gage housing

Photo 60. Instrumented Styrofoam panels in place on subgrade

Photo 61. Styrofoam HI 60-psi panels in place on subgrade

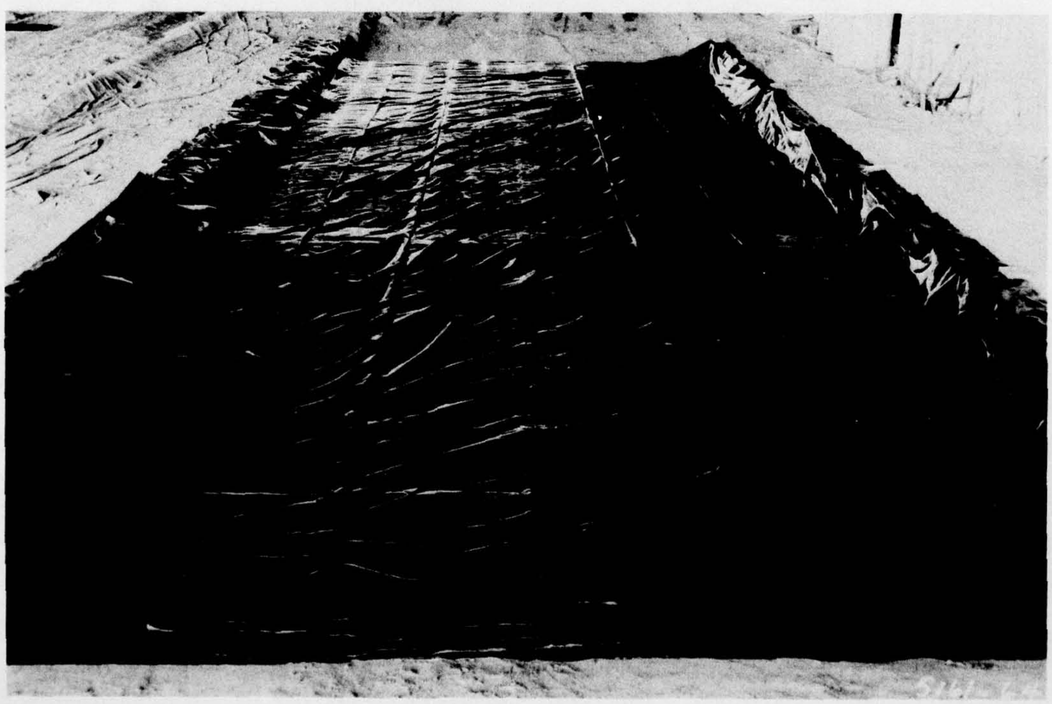


Photo 62. Styrofoam covered with 6-mil polyethylene membrane

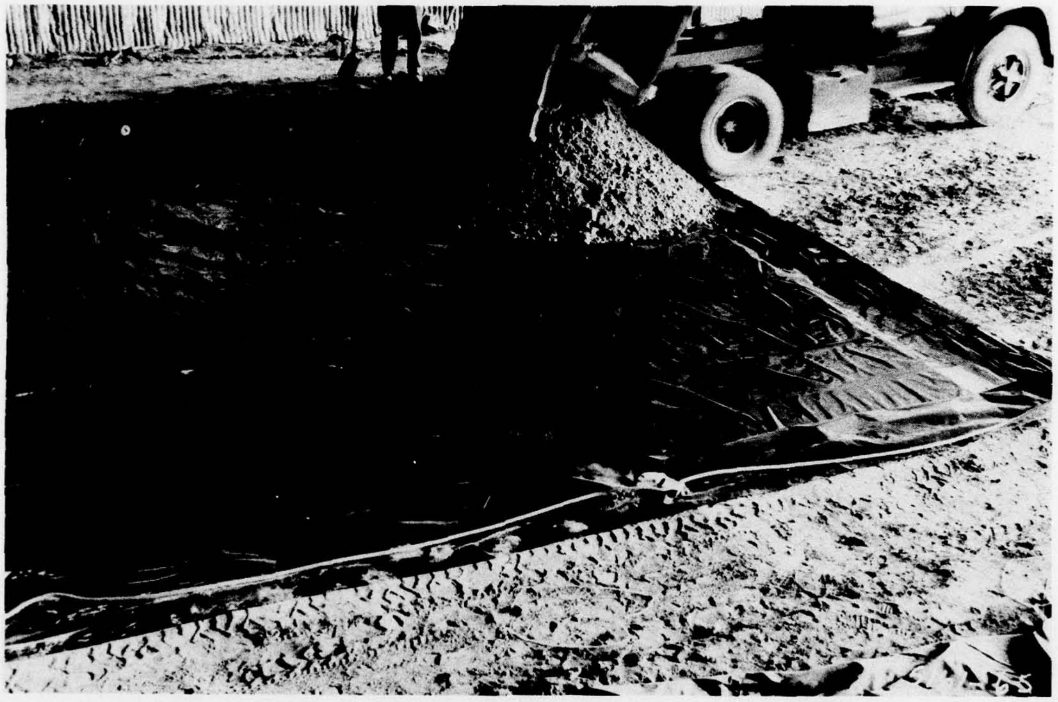


Photo 63. End dumping gravel on Styrofoam

Photo 64. Spreading gravel over Styrofoam with front-end loader

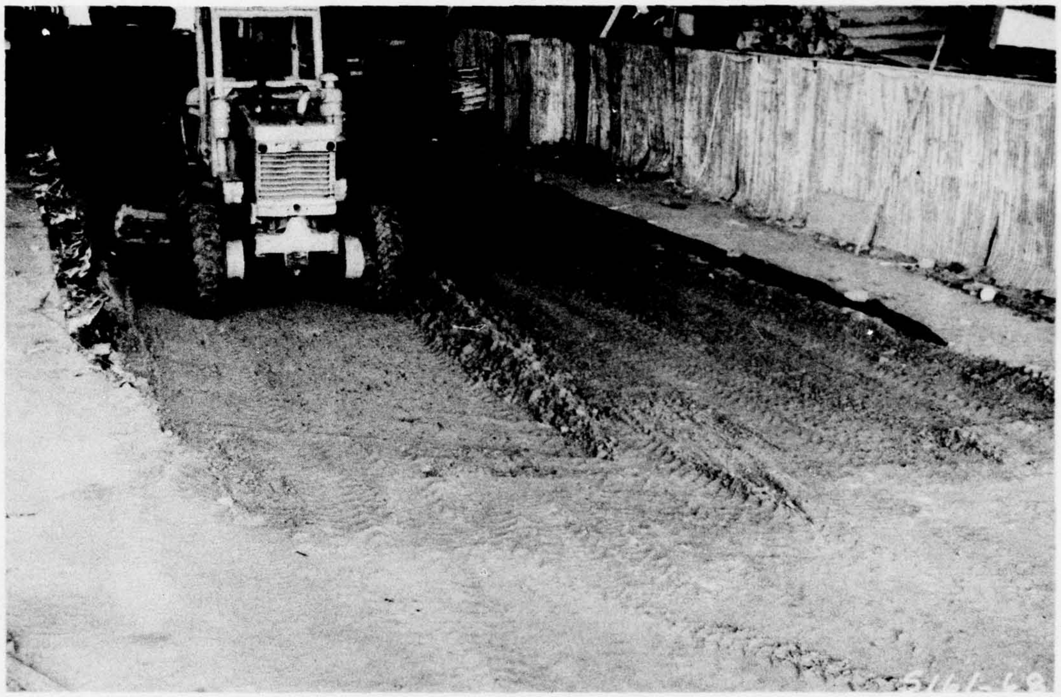


Photo 65. Grading gravel to desired thickness over Styrofoam

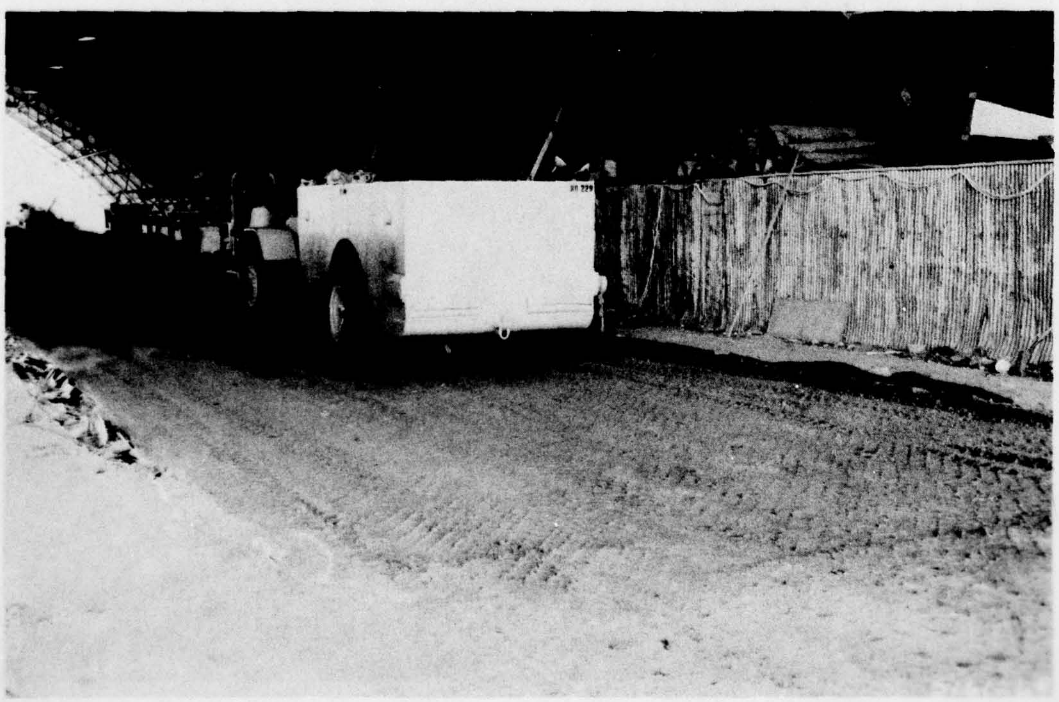
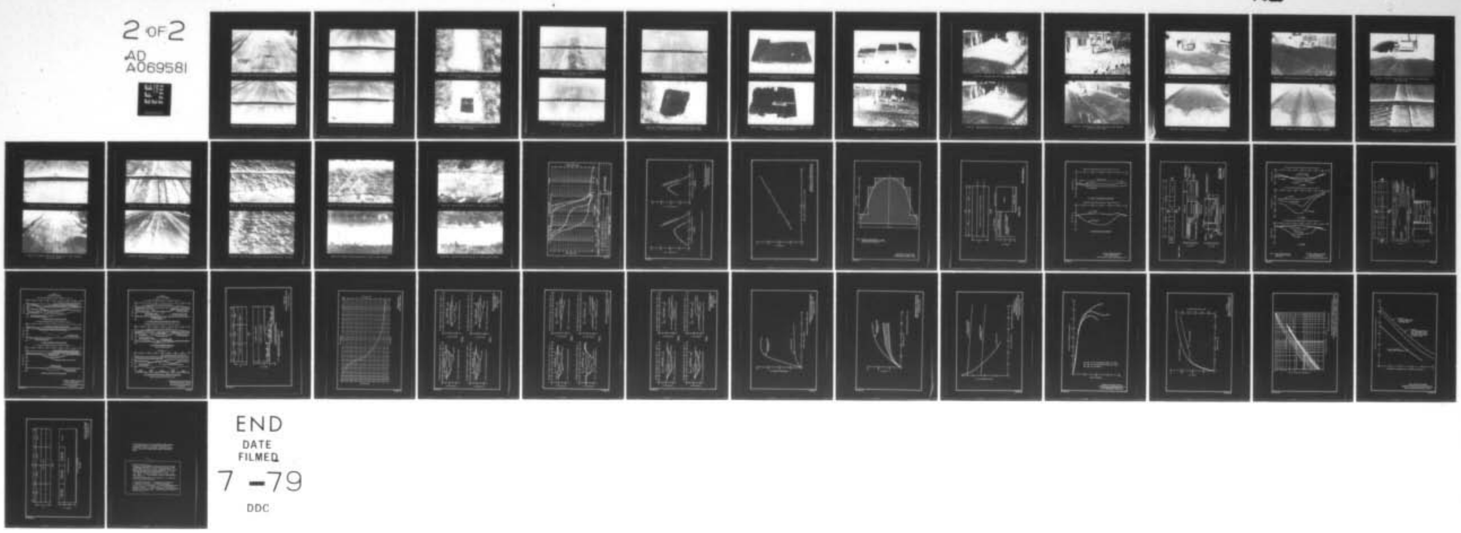


Photo 66. Compacting gravel subbase with 50-ton pneumatic roller

AD-A069 581 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 1/5
TRAFFIC TESTS OF EXPEDIENT AIRFIELD CONSTRUCTION CONCEPTS FOR P--ETC(U)
MAR 79 C D BURNS

UNCLASSIFIED WES-TR-GL-79-2 NL

2 OF 2
AD
A069581



END
DATE
FILMED
7-79
DDC

Photo 67. General view of completed Test Section No. 4 prior to traffic

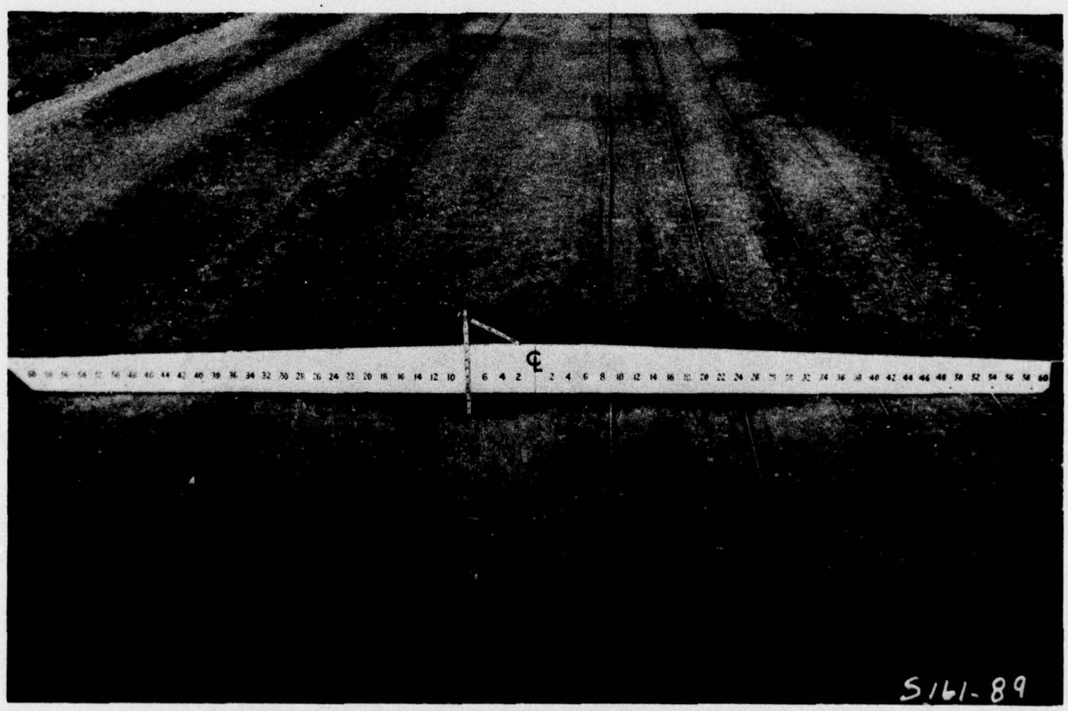


Photo 68. Test Section No. 4, item 1, after 480 passes of load wheel

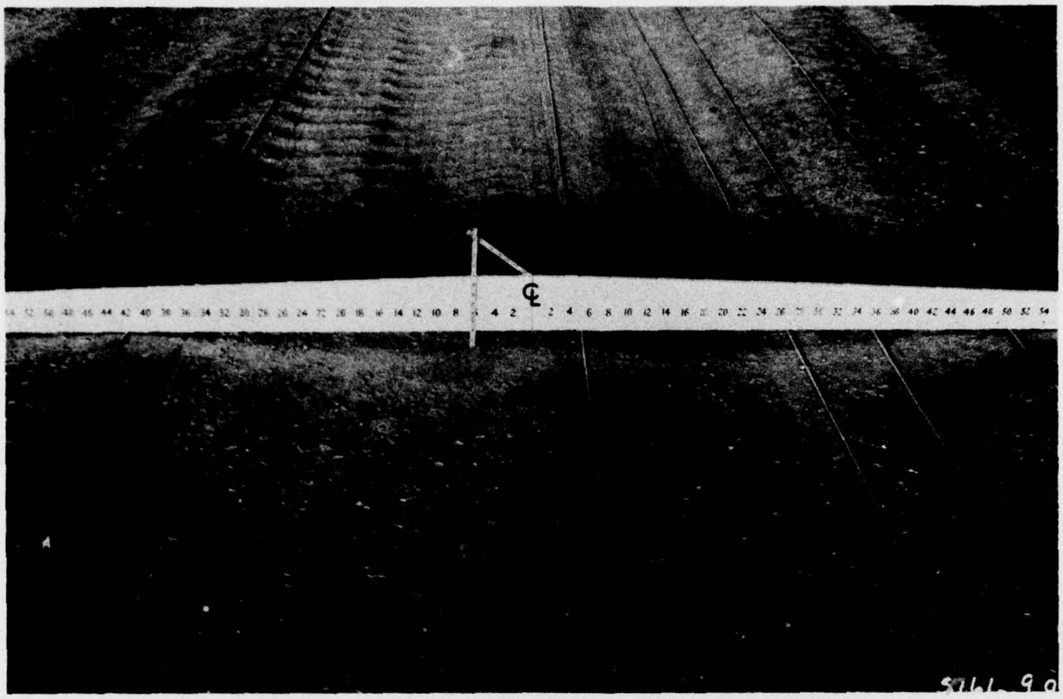


Photo 69. Test Section No. 4, item 2, after 480 passes of load wheel

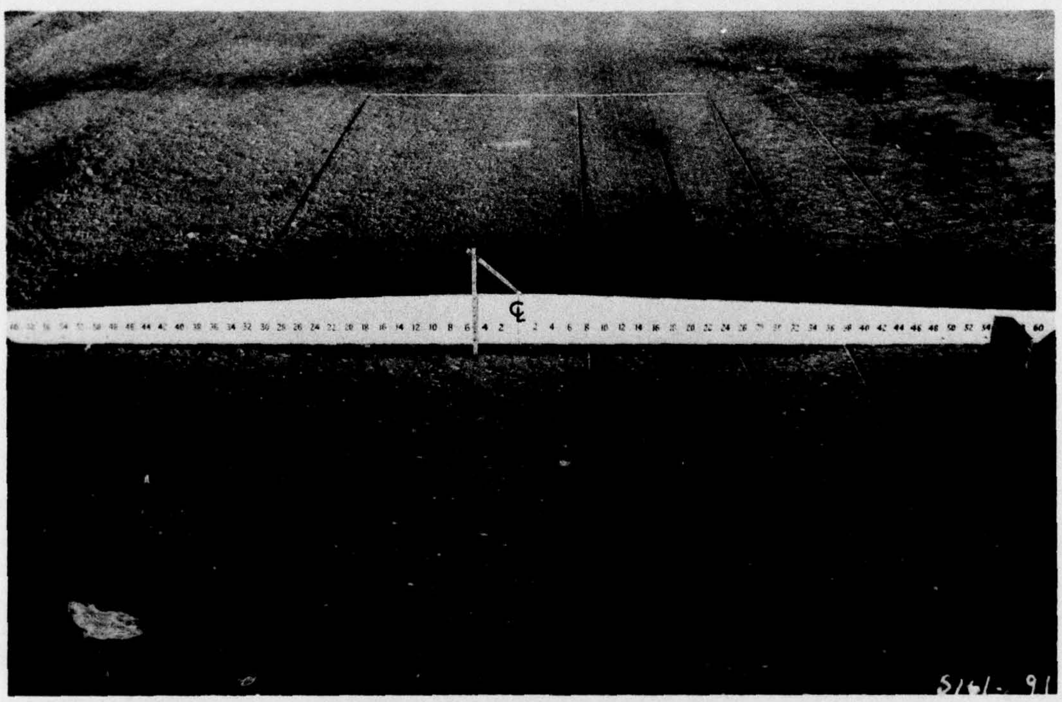


Photo 70. Test Section No. 4, item 3, after 480 passes of load wheel

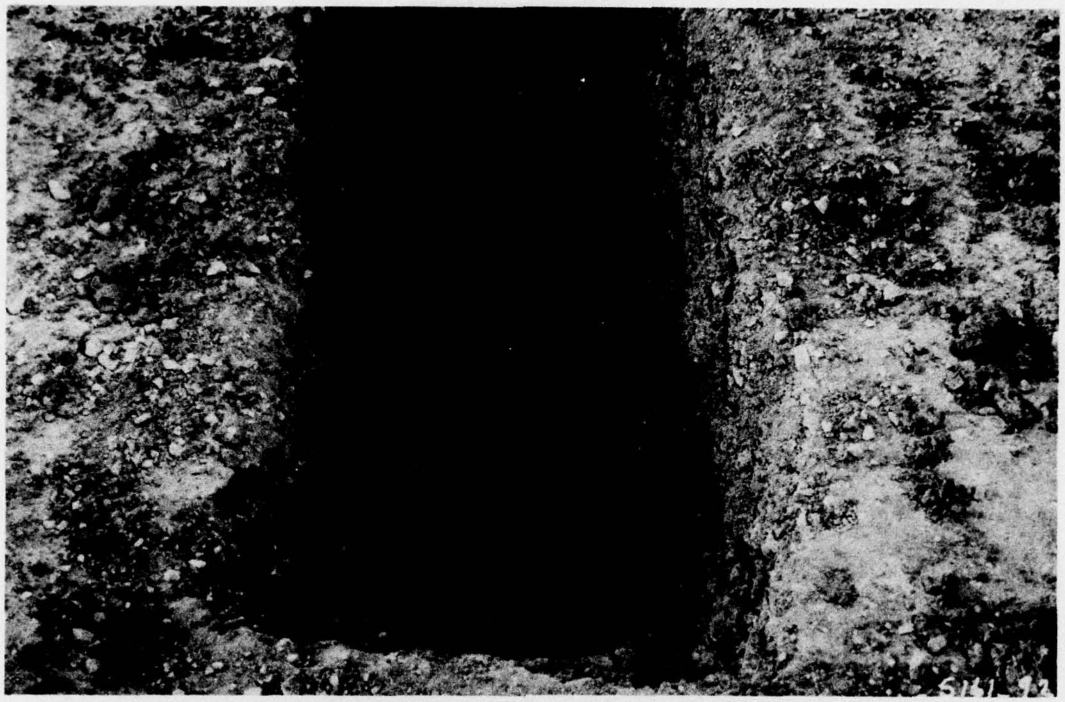


Photo 71. Trench in Test Section No. 4, item 1, showing condition of membrane after 480 passes

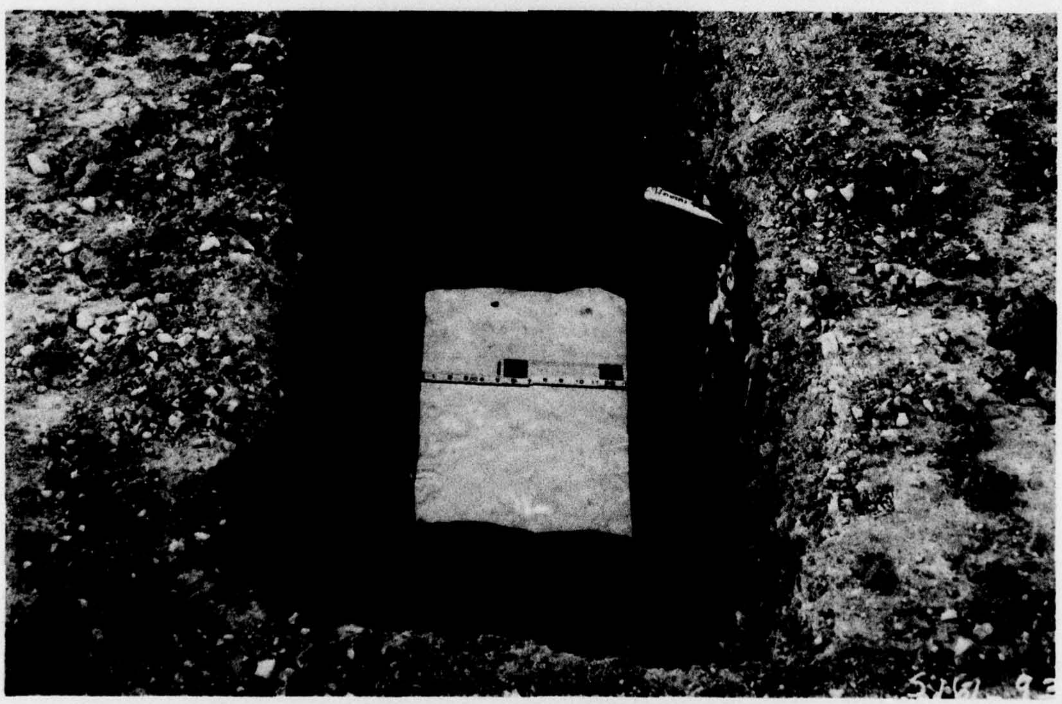


Photo 72. Surface of Styrofoam, Test Section No. 4., item 1, after 480 passes

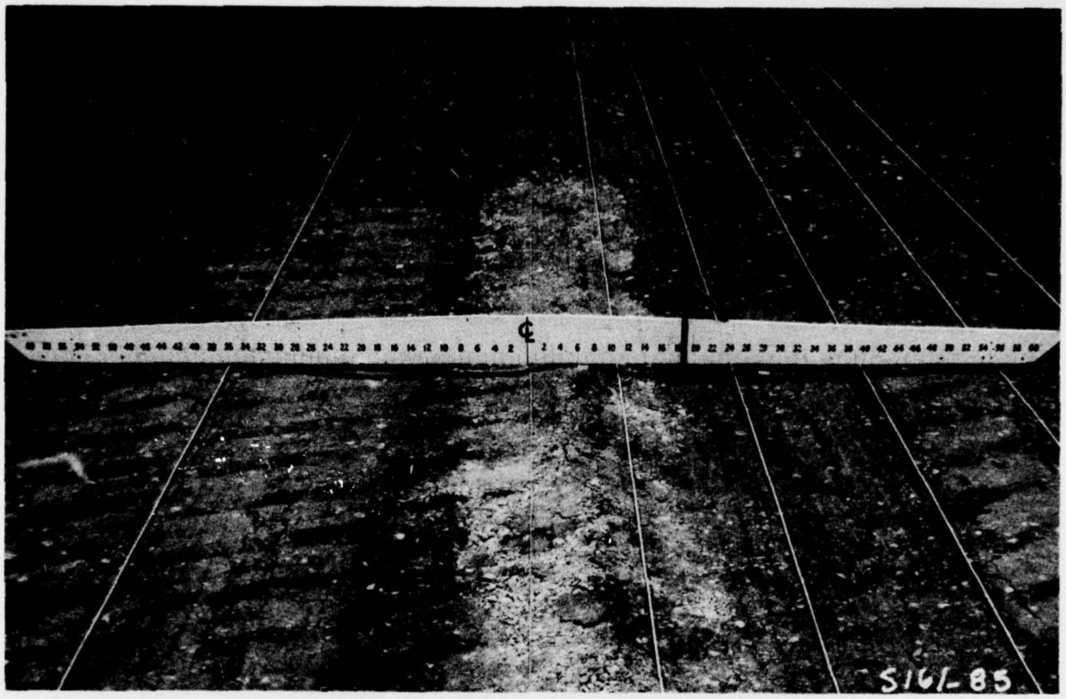


Photo 73. Test Section No. 4, item 1, 68 passes, after 6-in. base removed

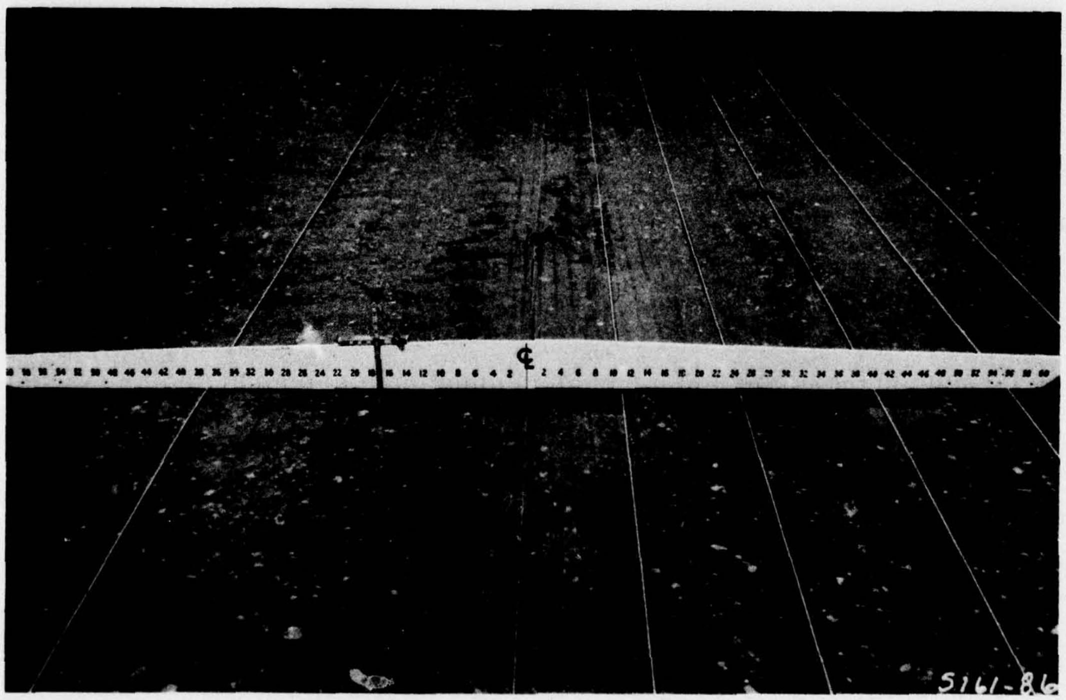


Photo 74. Test Section No. 4, item 2, 68 passes, after 6-in. base removed

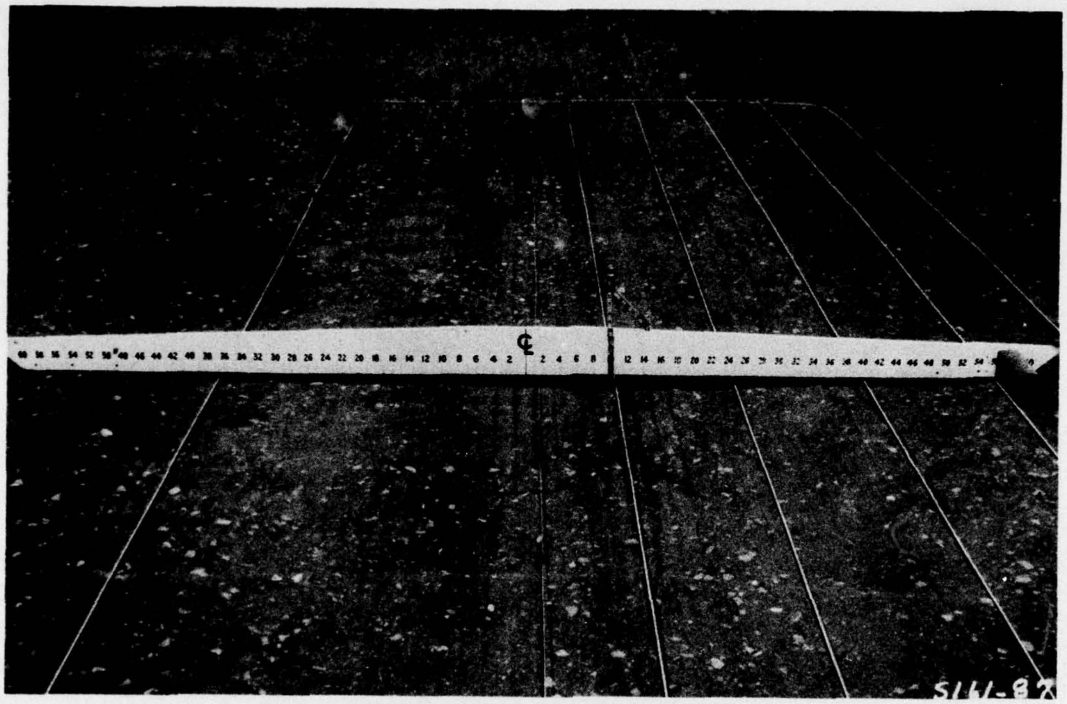


Photo 75. Test Section No. 4, item 3, 68 passes after 6-in. base removed

Photo 76. Difference in surface texture around gage in Test Section No. 4, item 1; gage protected by 1-in. cover of sand

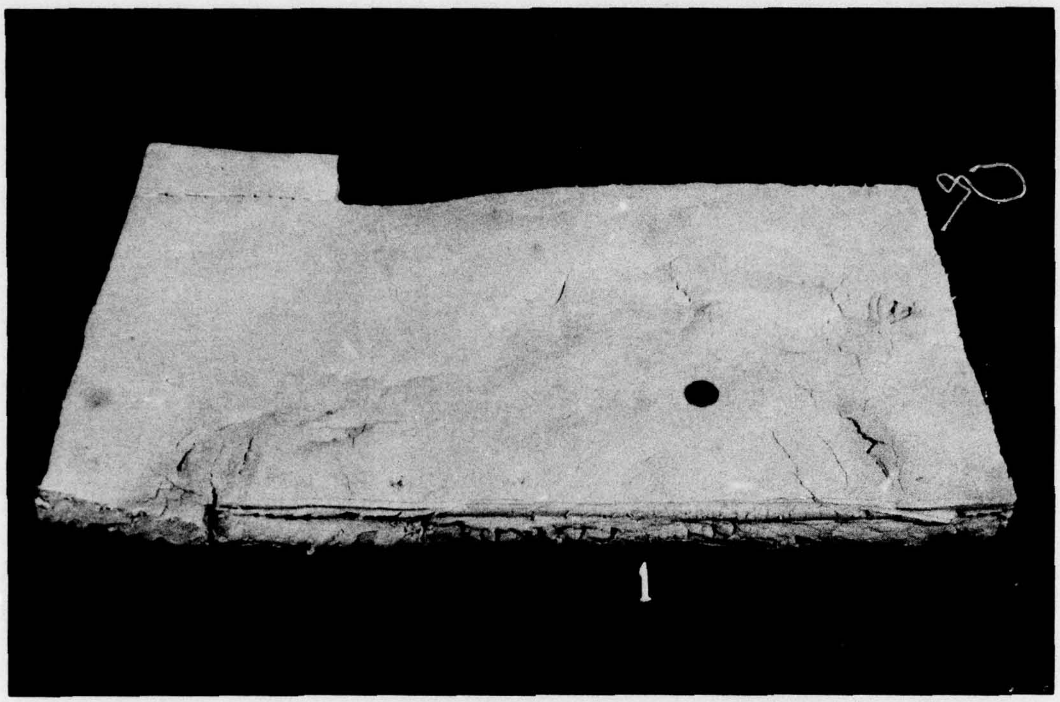


Photo 77. Styrofoam cut from Test Section No. 4, item 1, after reduced thickness and all traffic

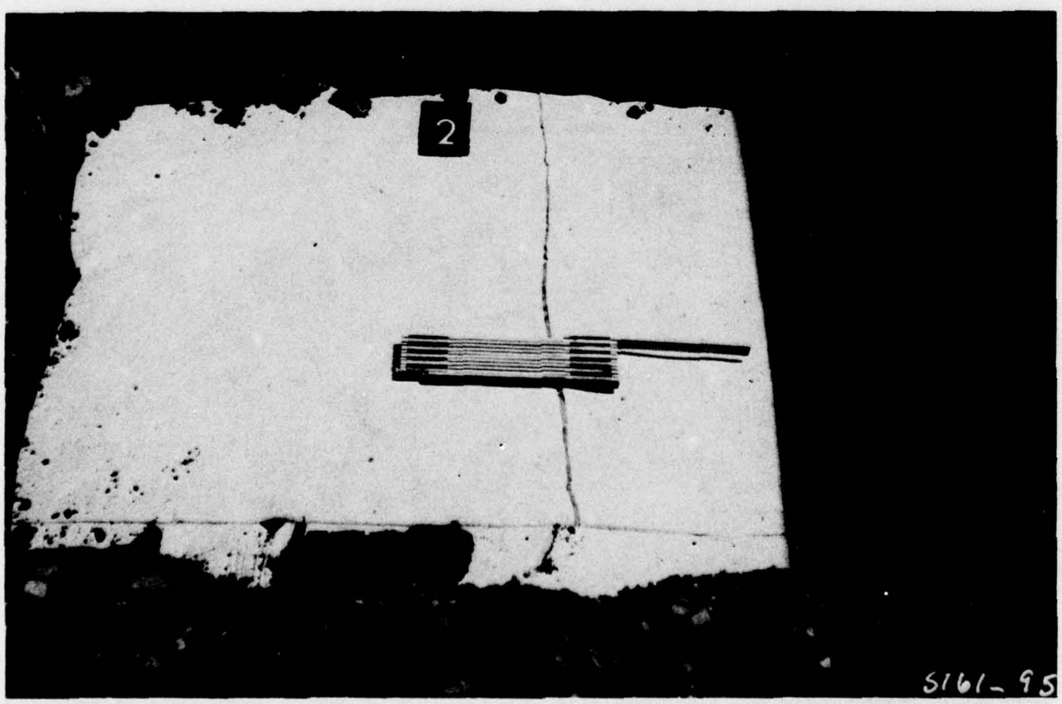


Photo 78. Break in Styrofoam in Test Section No. 4, item 2, after reduced thickness and all traffic

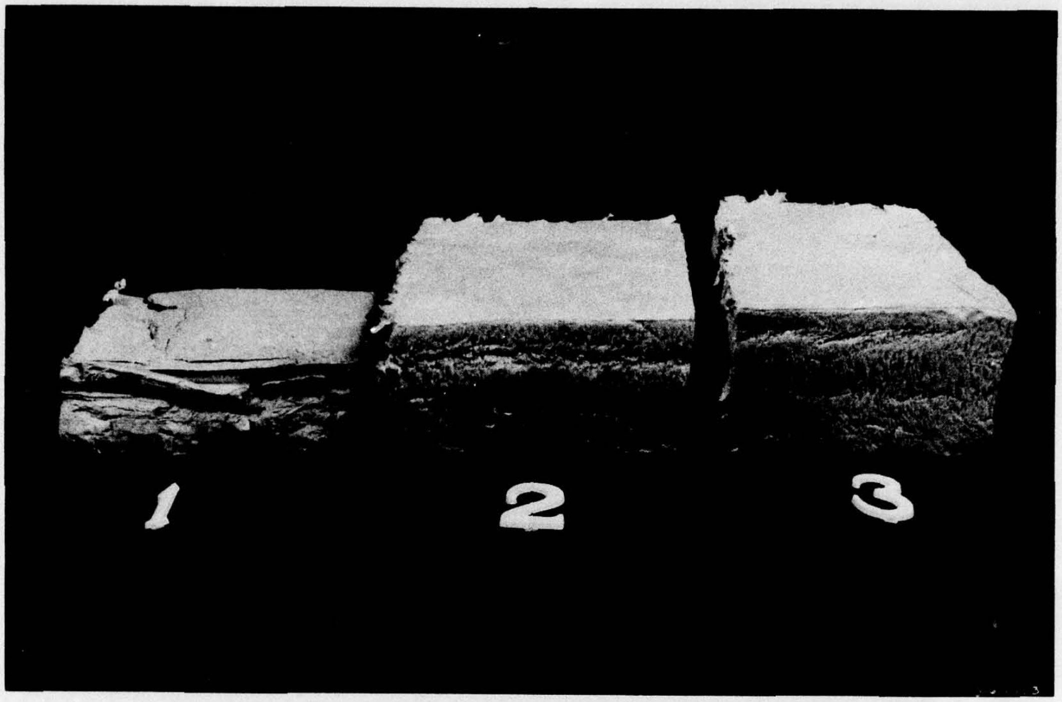


Photo 79. Comparative compression in Styrofoam cut from Test Section No. 4, items 1, 2, and 3, after reduced thickness of base and all traffic

Photo 80. Spreading sand with D-4 tractor

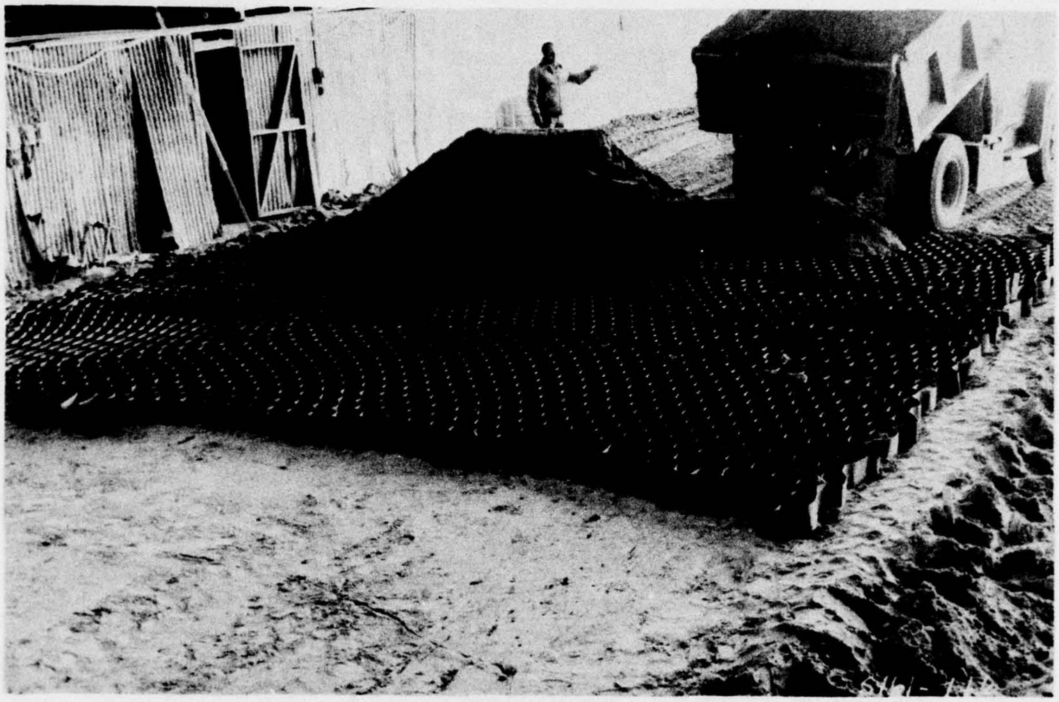


Photo 81. Dumping sand into 6-in. paper grid

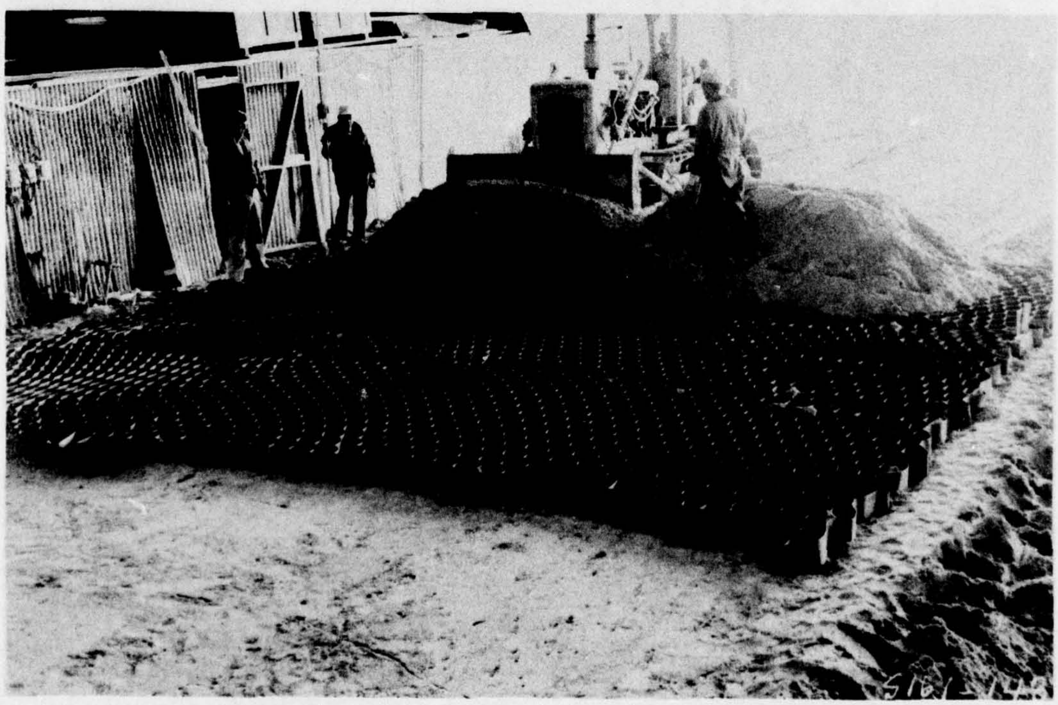


Photo 82. Spreading sand into 6-in. grids with D-4 tractor

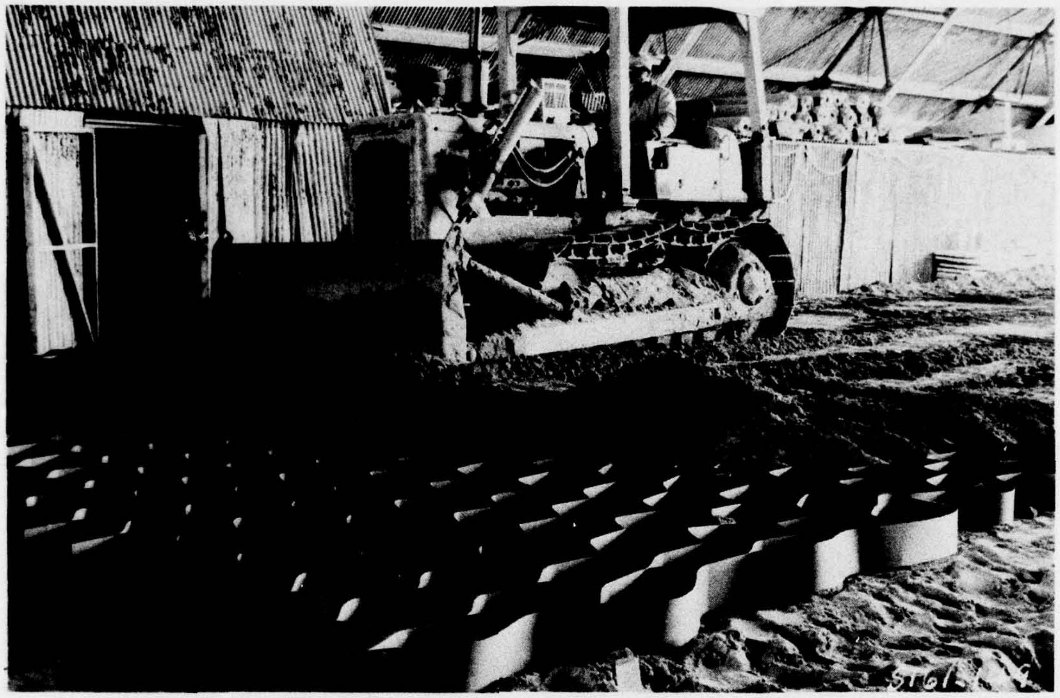


Photo 83. Spreading sand into 12-in. grid with D-4 tractor

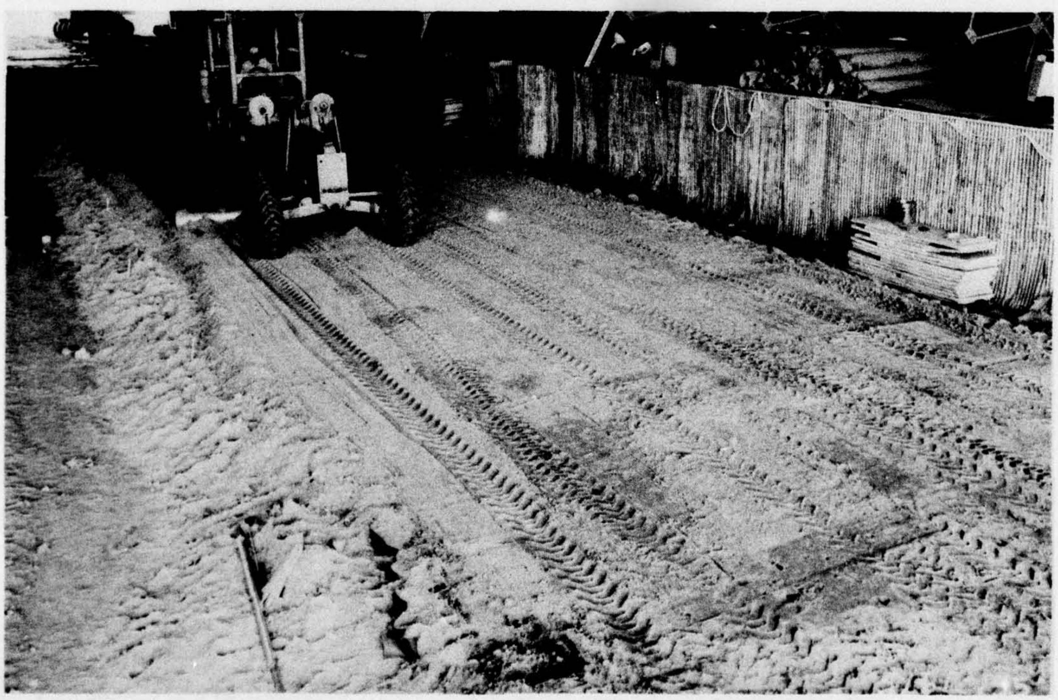


Photo 84. Grading excess sand from top of grid leaving 1-1/2- to 2-in. cover

Photo 85. Compacting sand into grid with 50-ton pneumatic roller

Photo 86. General view of Test Section No. 5 prior to traffic

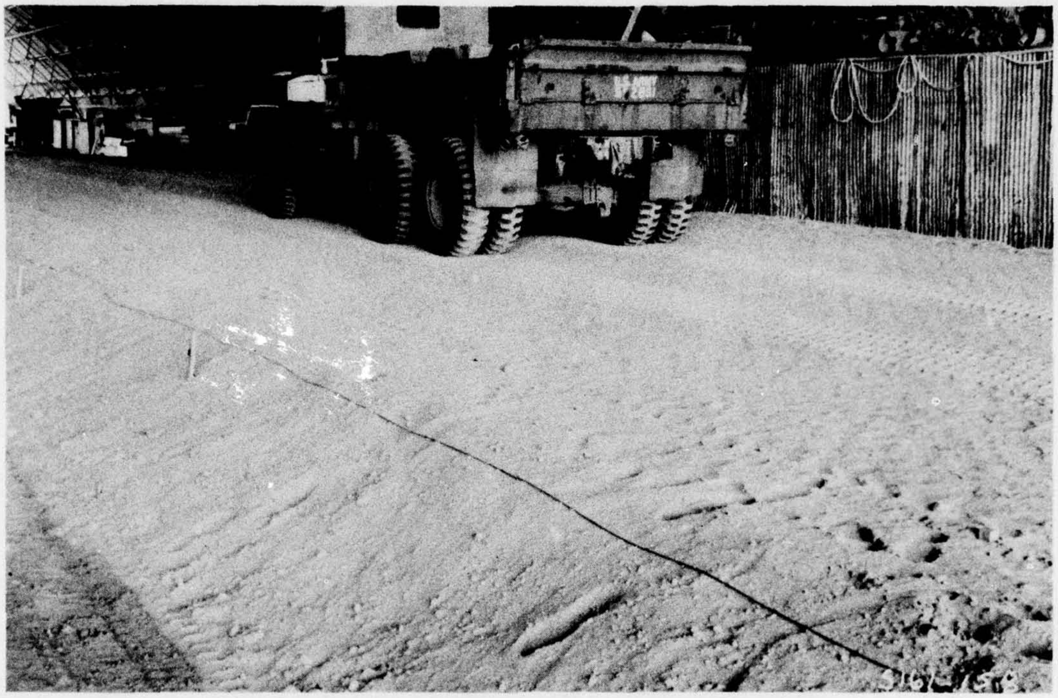


Photo 87. Traffic being applied with 40-kip, 6 x 6 military truck

Photo 88. General view of Test Section No. 5 after traffic

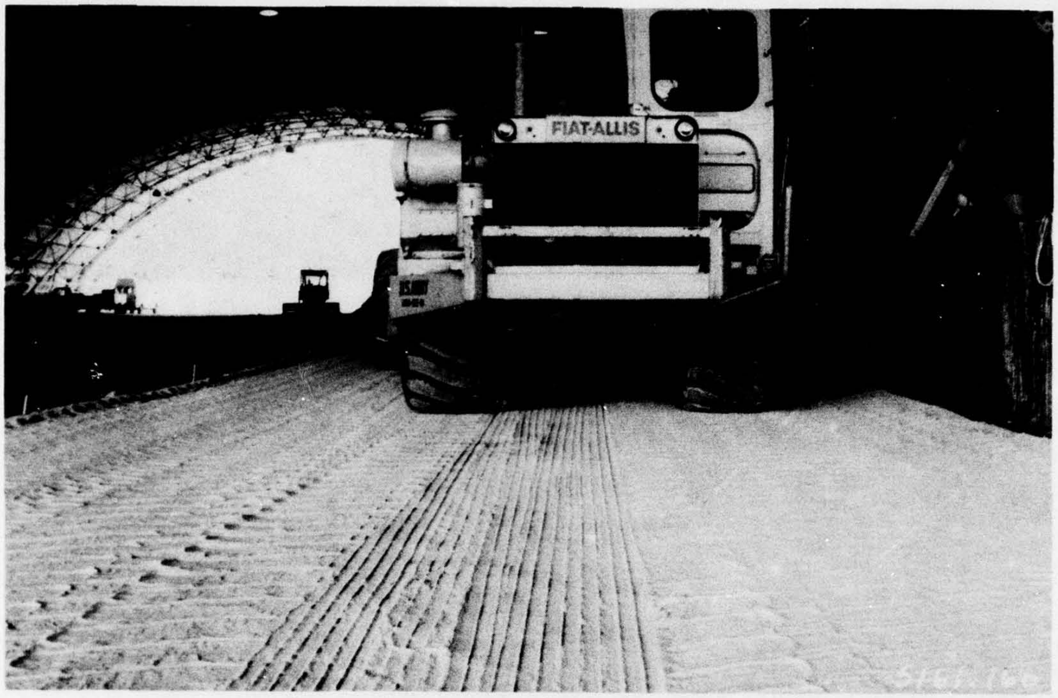


Photo 89. Traffic being applied with 70-kip, single-tandem gear test cart

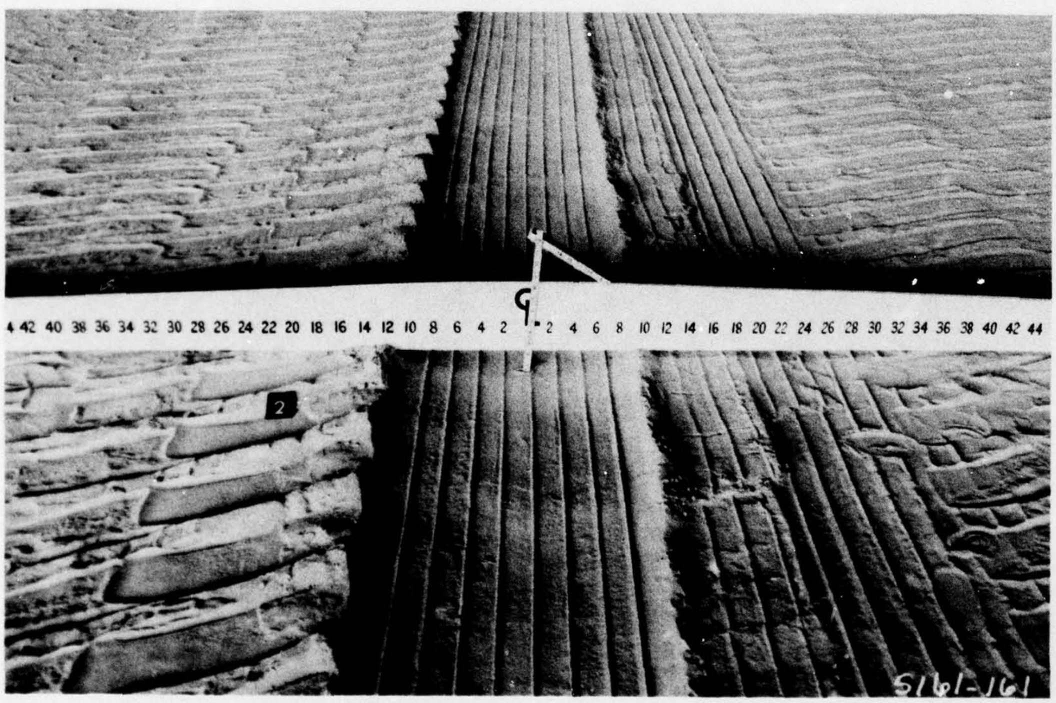


Photo 90. Two- and one-half-inch rut in Test Section No. 5, item 2, under C-130 traffic

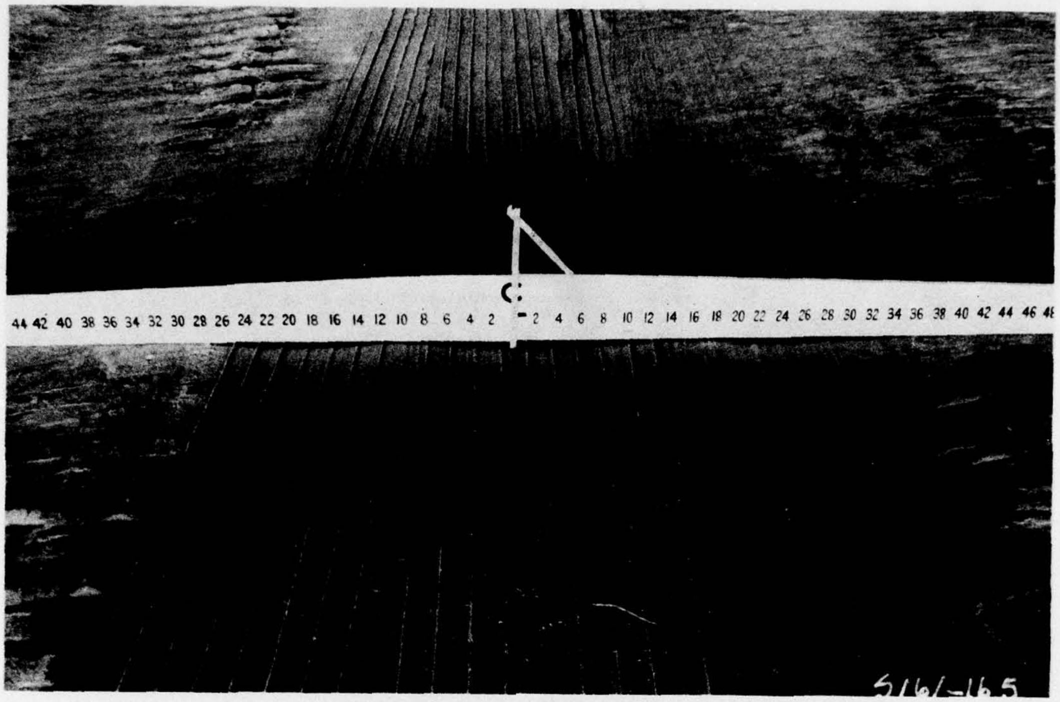


Photo 91. Test Section No. 5, item 4, after C-130 traffic

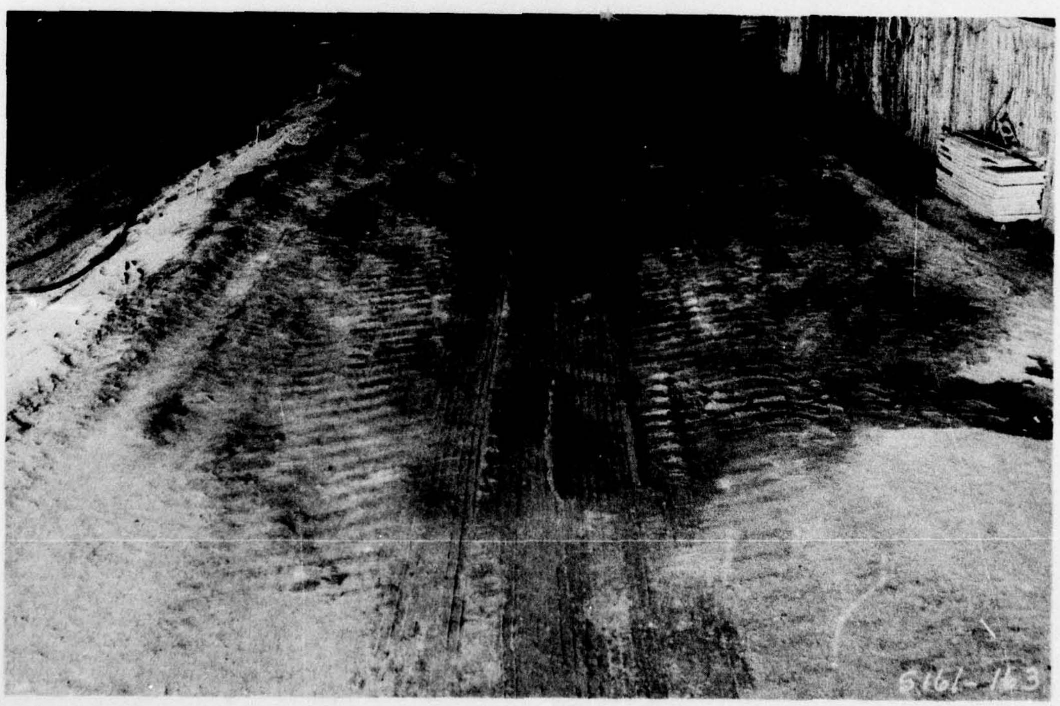


Photo 92. Overall view of Test Section No. 5 after wetting and C-130 traffic

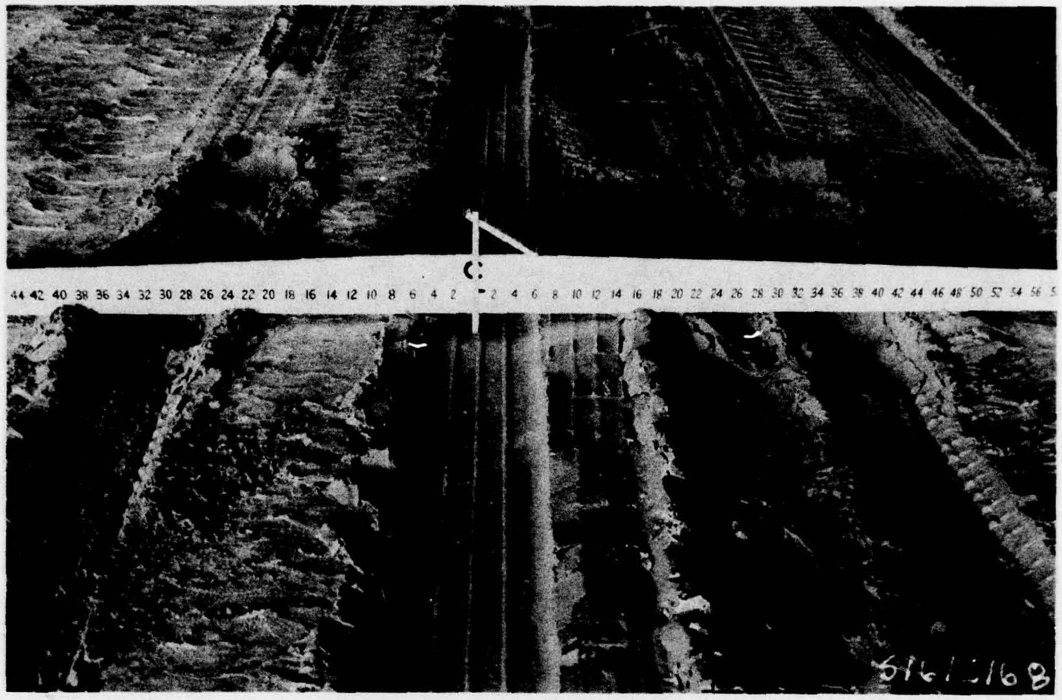


Photo 93. Rut in Test Section No. 5, item 2, after F-4C traffic

Photo 94. General view of Test Section No. 5 after four passes of F-4C load cart

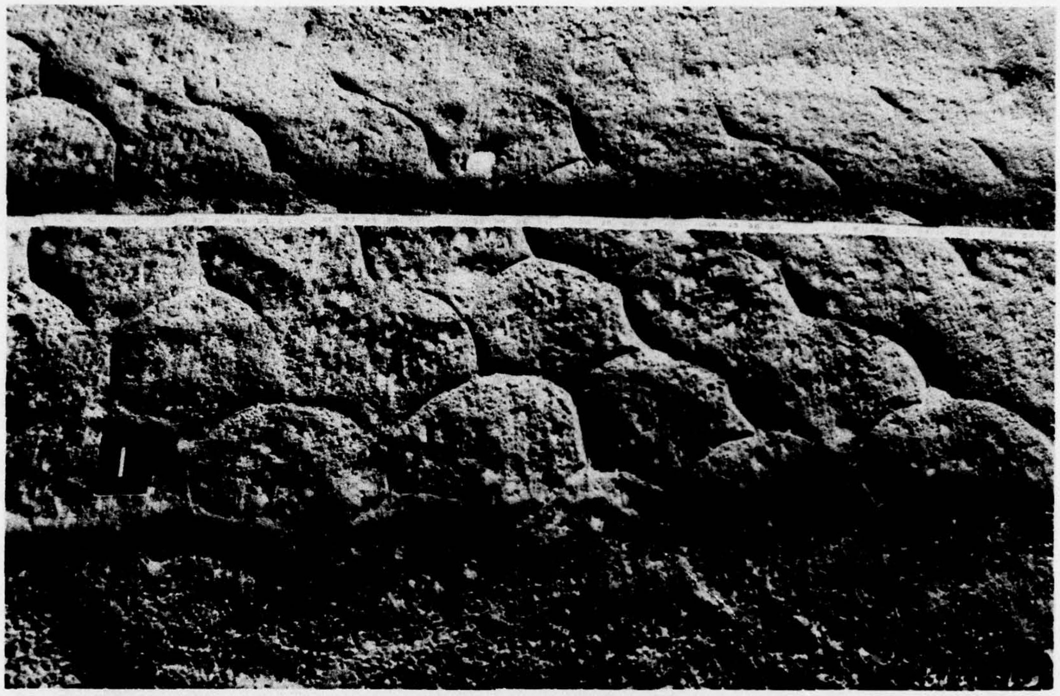


Photo 95. Top of 6- by 6- by 6-in. grid in Test Section No. 5, item 1

Photo 96. Top of 8- by 8- by 6-in. grid in Test Section No. 5, item 2

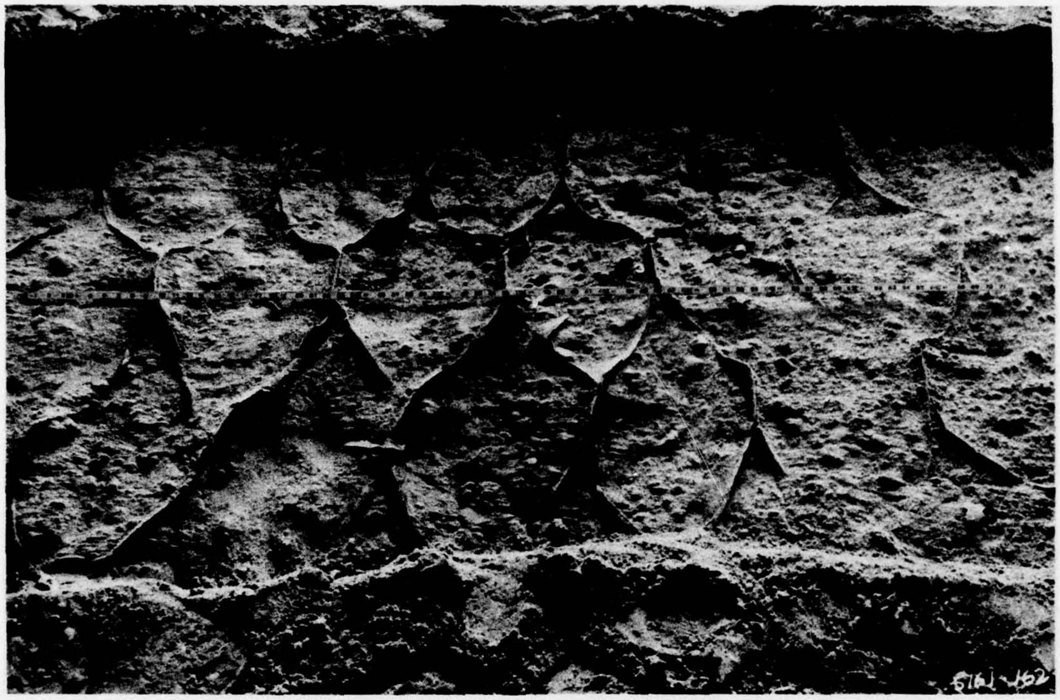


Photo 97. Top of 12- by 12- by 6-in. grid in Test Section No. 5, item 3

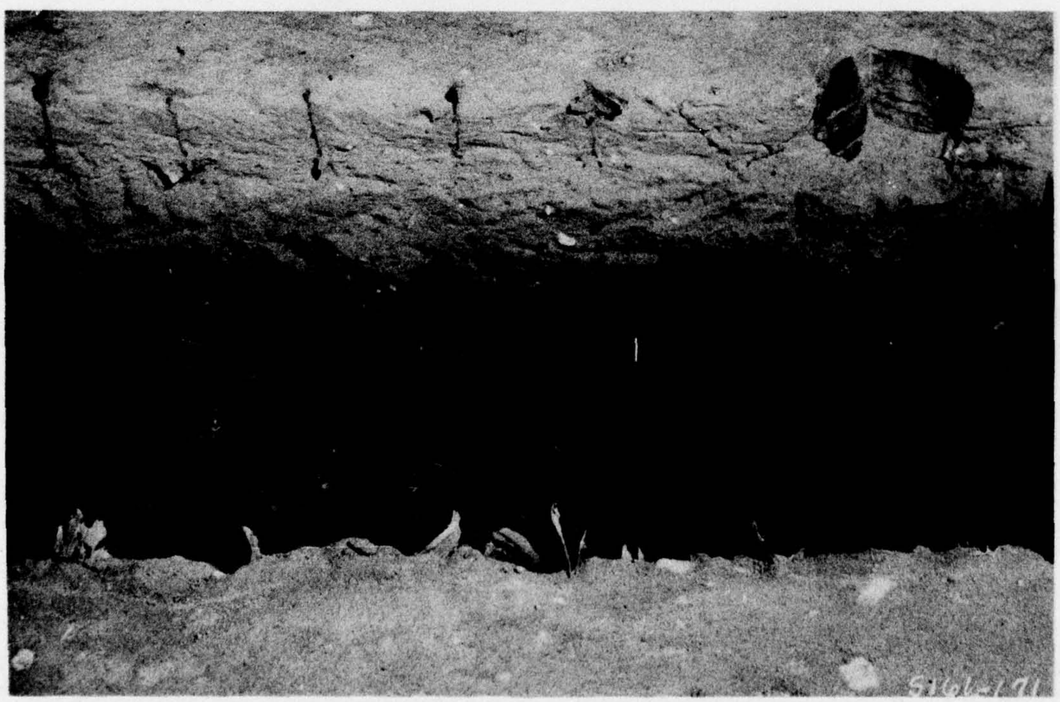
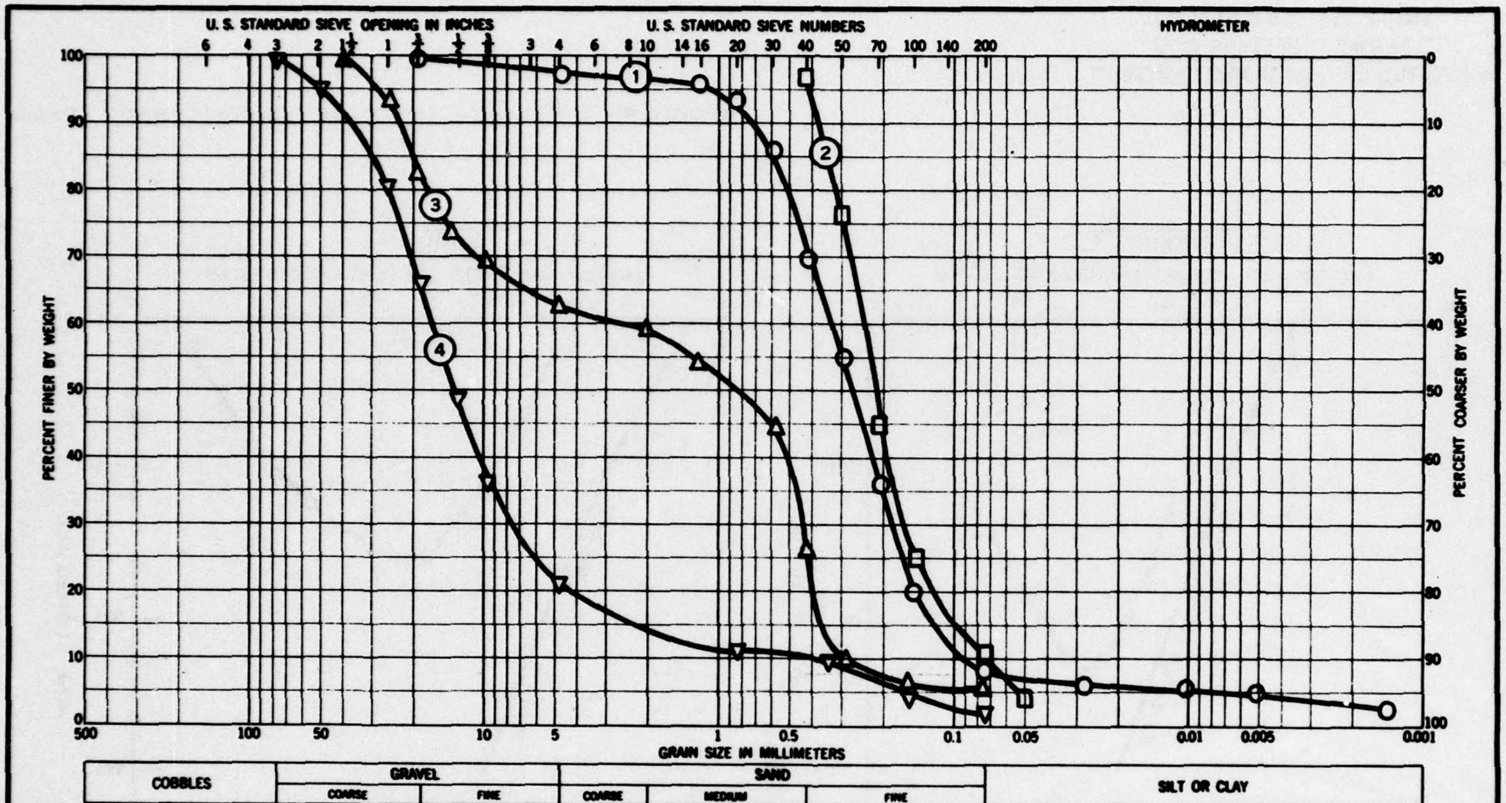


Photo 98. Trench in Test Section No. 5, item 1, after traffic

Photo 99. Trench in Test Section No. 5, item 2, after traffic

Photo 100. Trench in Test Section No. 5, item 3, after traffic



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

1 – ○ AS USED IN TEST SECTION (SAND SP) NP
2 – □ SAND GRADATION FURNISHED BY CRREL (2 SEP 77) WET SAND IN BORROW
3 – △ GRAVELLY SAND USED IN TEST SECTION
4 – ▽ COLVILLE RIVER GRAVEL, GRADATION FURNISHED BY CRREL

Project

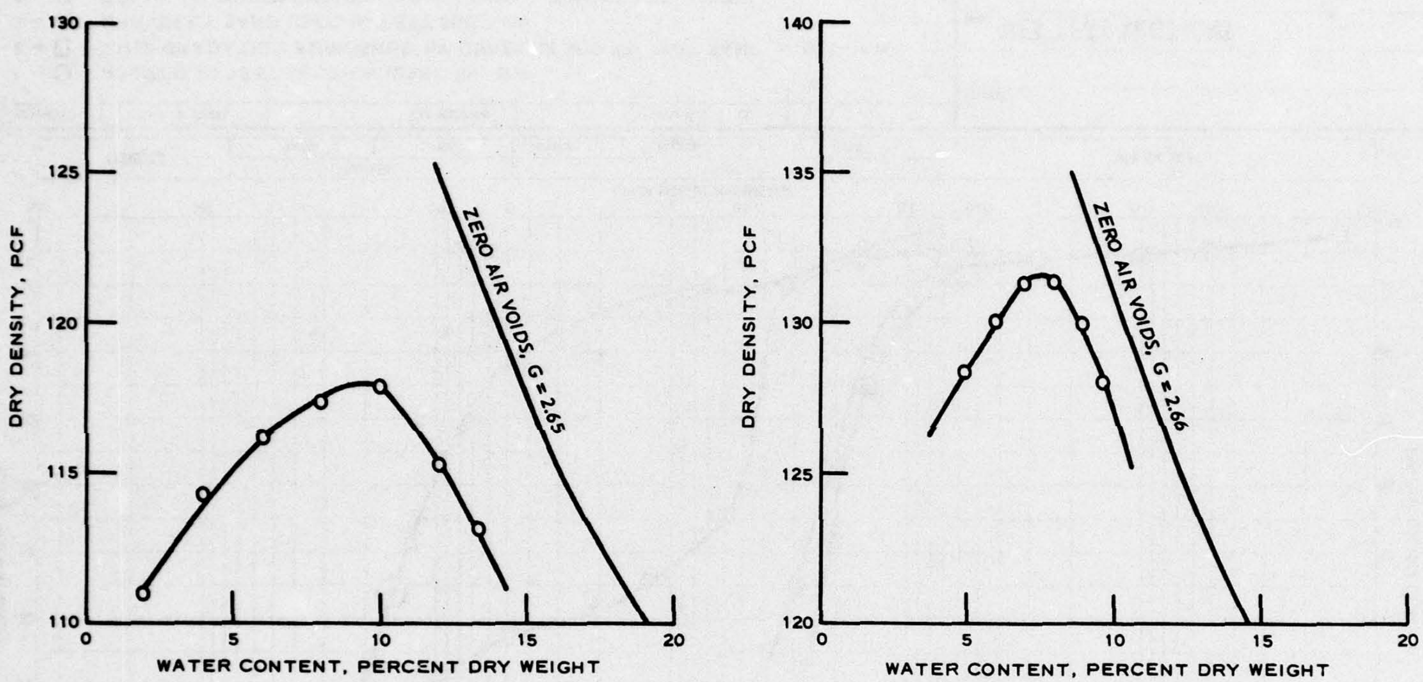
Area **WES TEST SECTIONS**

Boring No.

Date

GRADATION CURVES

PLATE I

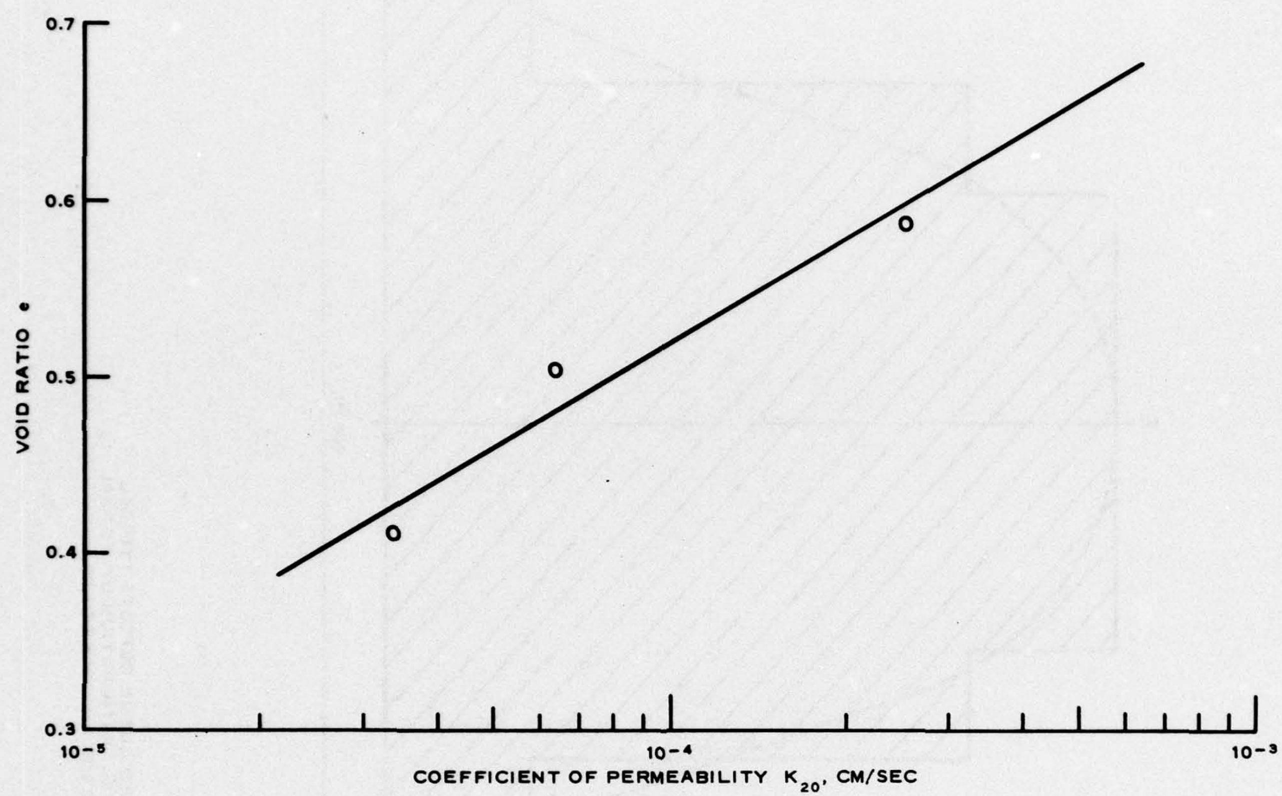


a. SAND

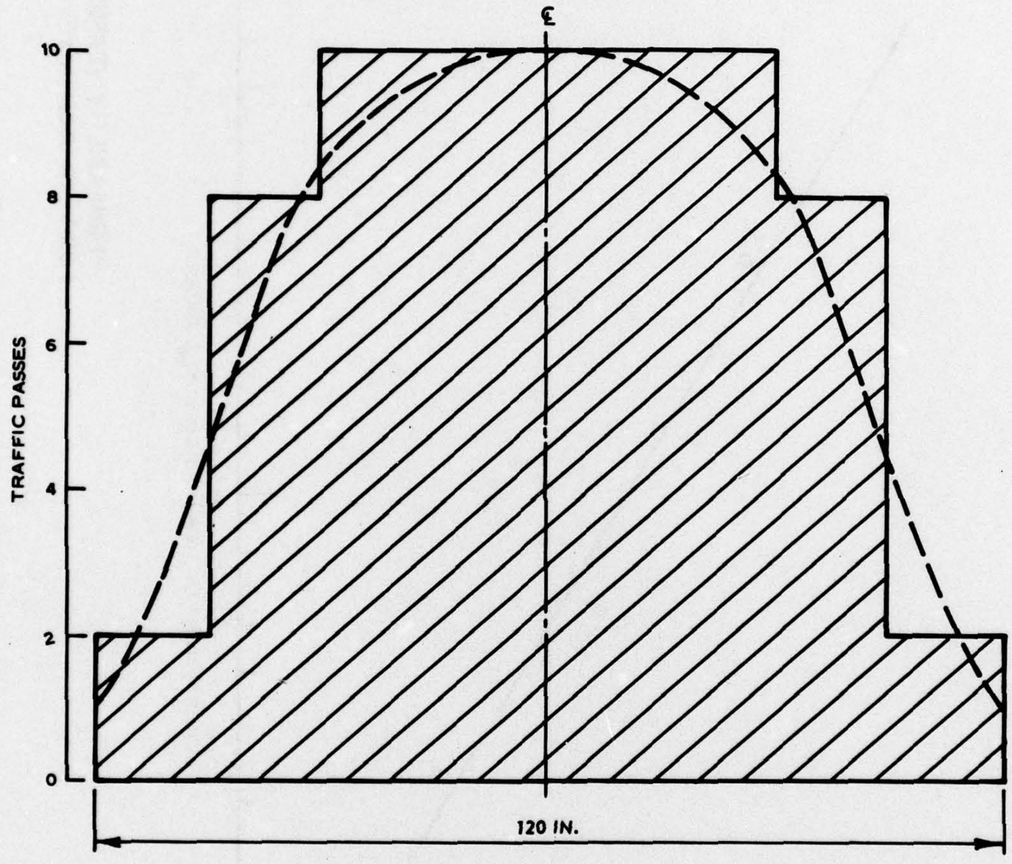
b. GRAVEL

NOTE: COMPACTION EFFORT CE 55 (ASTM D1557, METHOD D)

LABORATORY COMPACTION DATA
FOR SAND AND GRAVEL
USED IN TEST SECTIONS

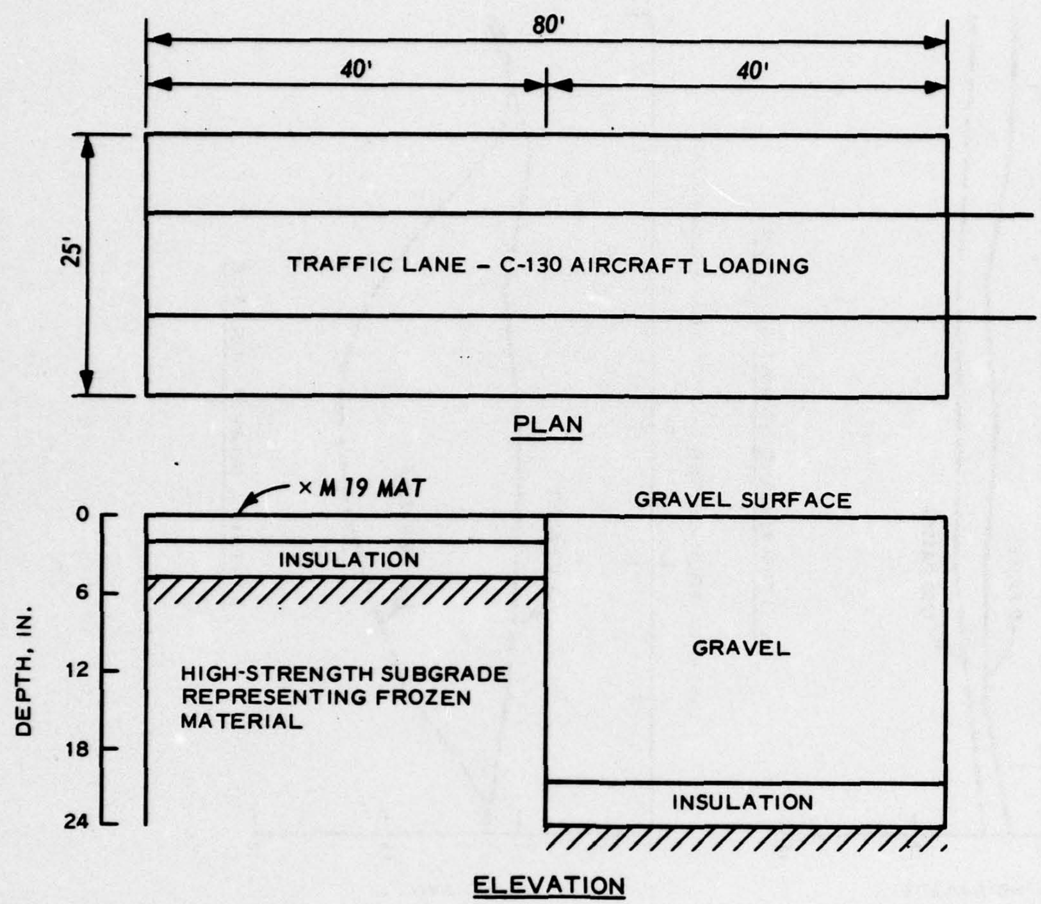


PERMEABILITY VERSUS VOID RATIO
FOR SAND USED IN WES TEST SECTION

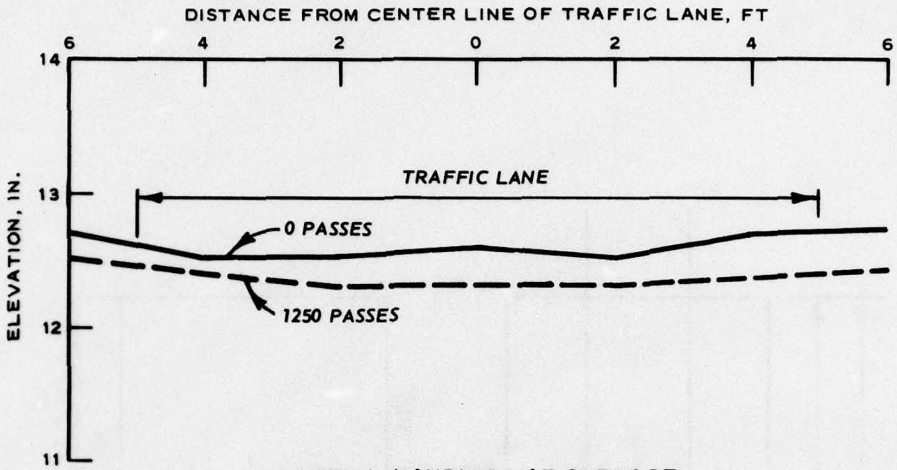


NOTE: DASHED CURVE DEPICTS TYPICAL NORMAL DISTRIBUTION OF ACTUAL LANDINGS AND TAKEOFFS.

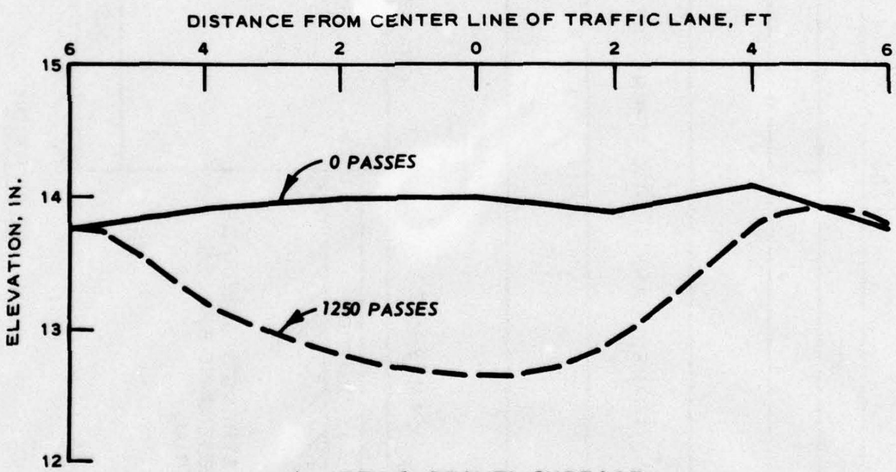
TRAFFIC PATTERN FOR
35-KIP SINGLE-WHEEL LOAD



TEST SECTION NO. 1

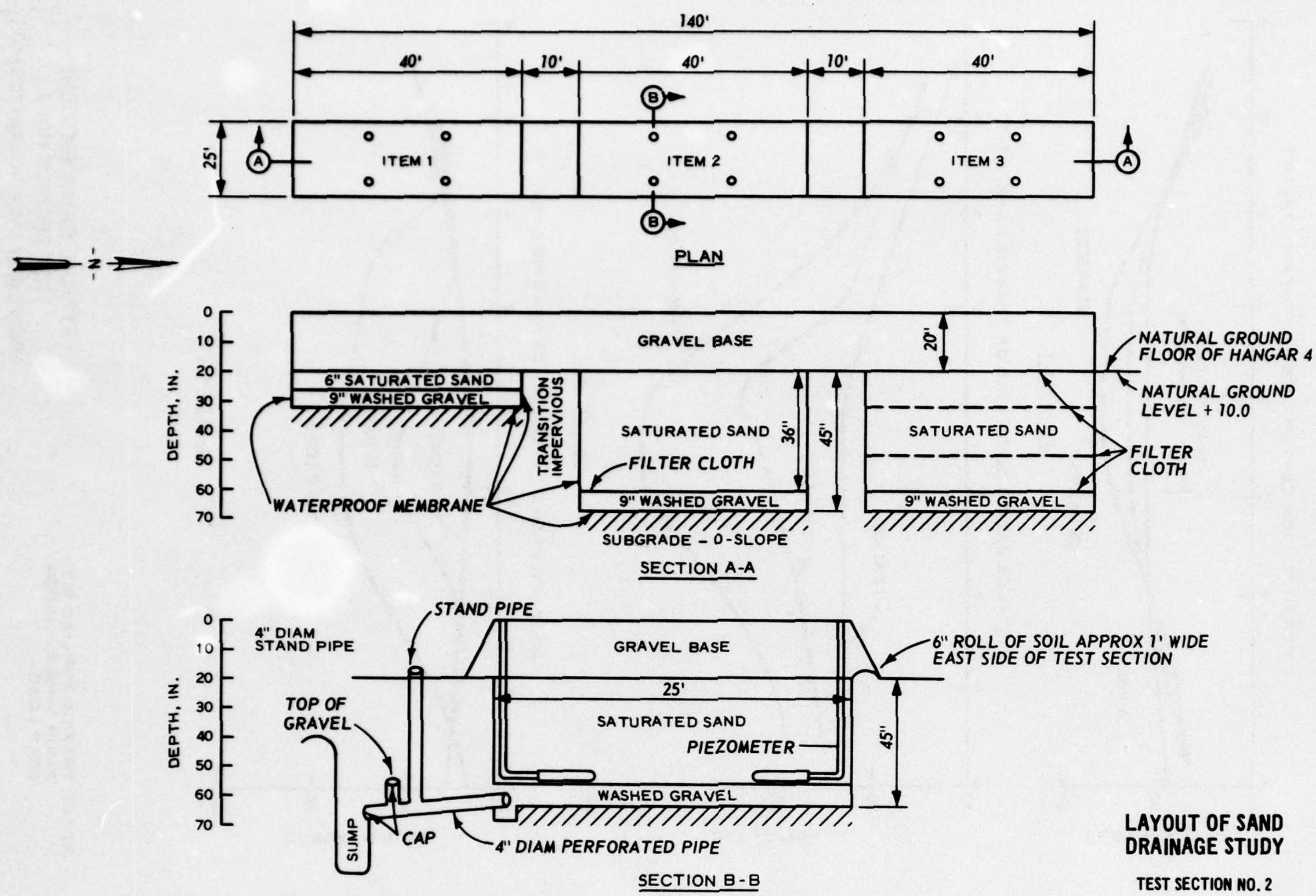


a. ITEM 1, LANDING MAT SURFACE



b. ITEM 2, GRAVEL SURFACE

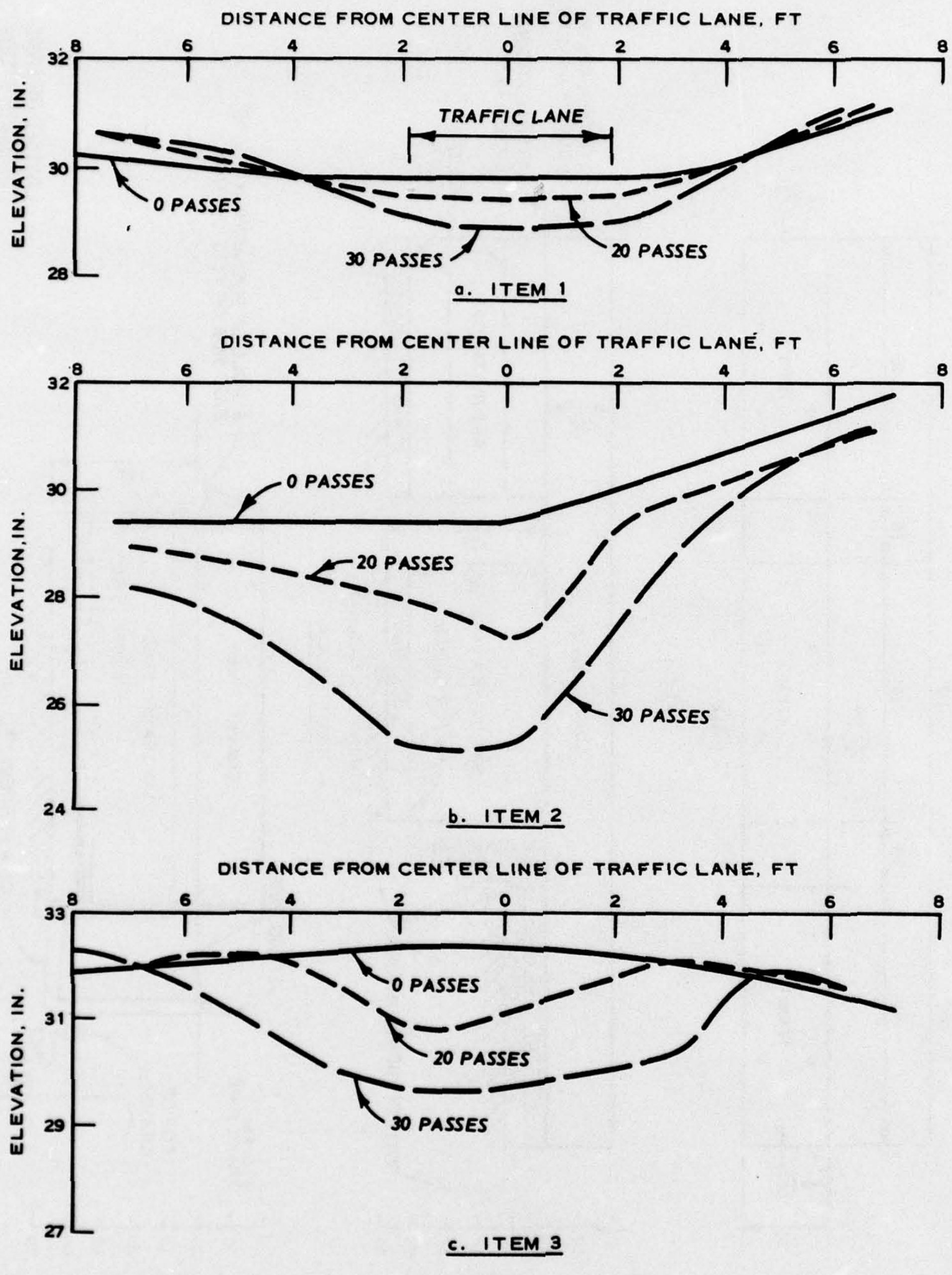
TYPICAL CROSS SECTIONS
TEST SECTION NO. 1
MAT AND GRAVEL OVER STYROFOAM INSULATION



LAYOUT OF SAND DRAINAGE STUDY

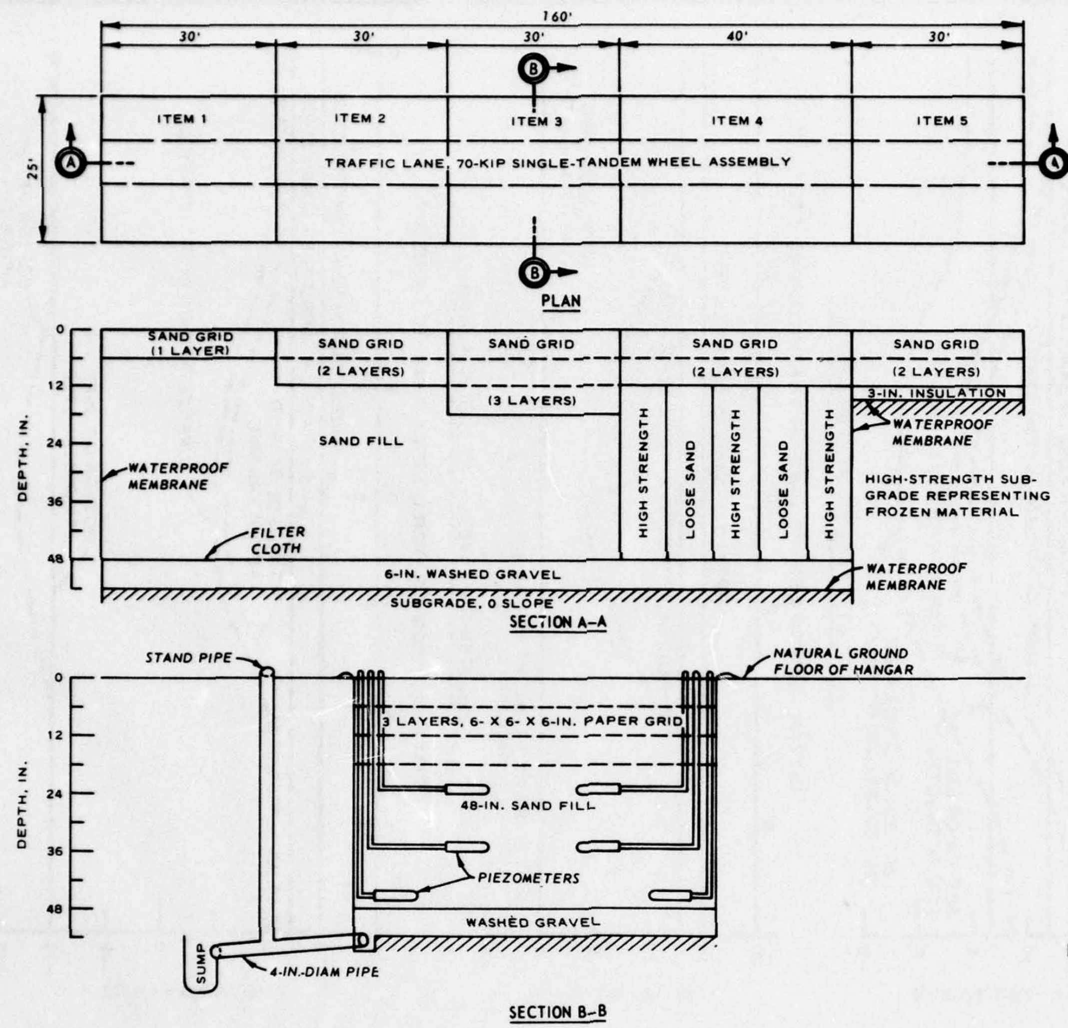
TEST SECTION NO. 2

PLATE 7



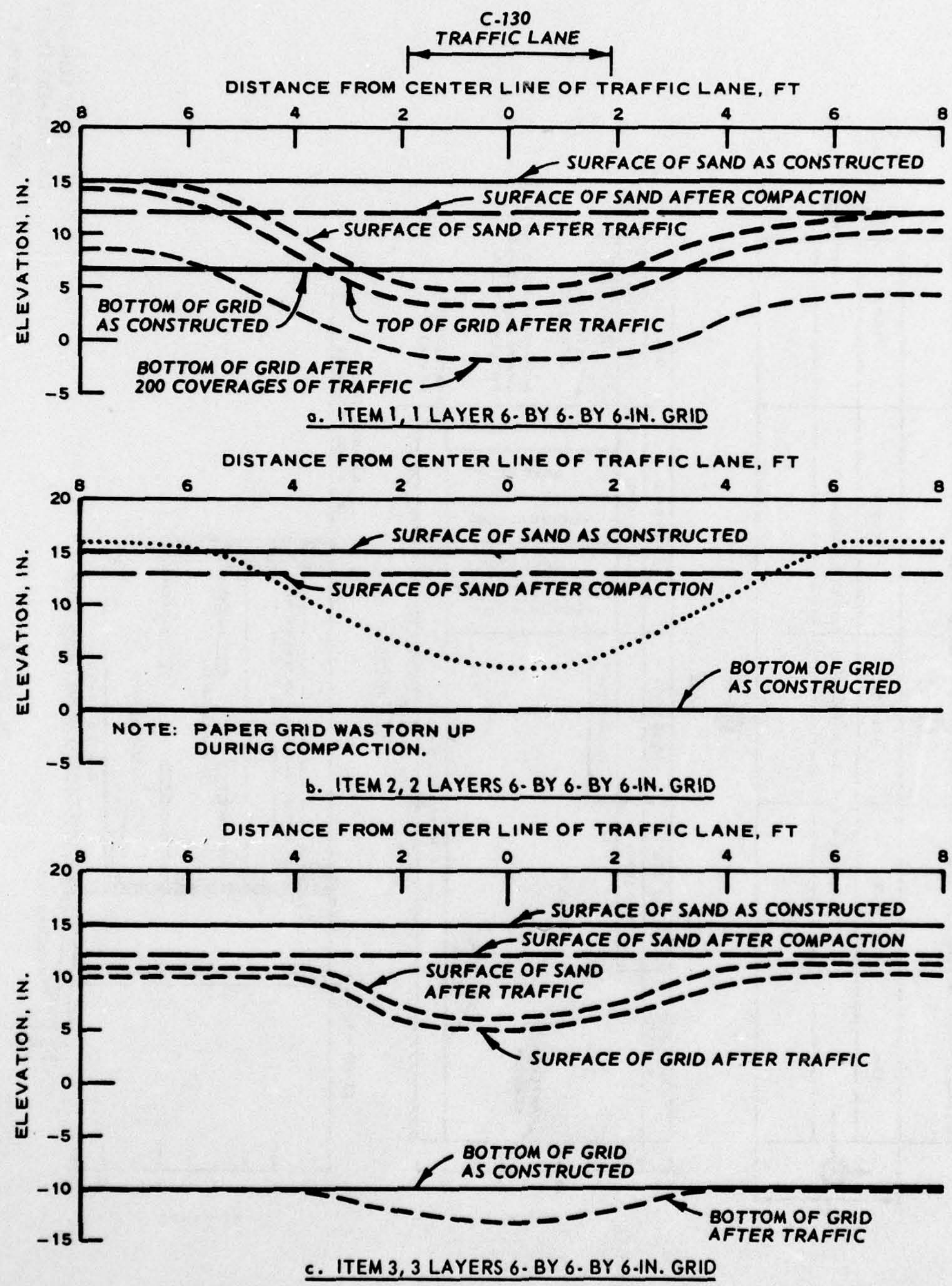
NOTE: TRAFFIC APPLIED WITH 70-KIP SINGLE-TANDEM GEAR LOAD.

TYPICAL CROSS SECTIONS
TEST SECTION NO. 2
GRAVEL BASE OVER SATURATED SAND



LAYOUT OF SAND-GRID CONFINEMENT STUDY

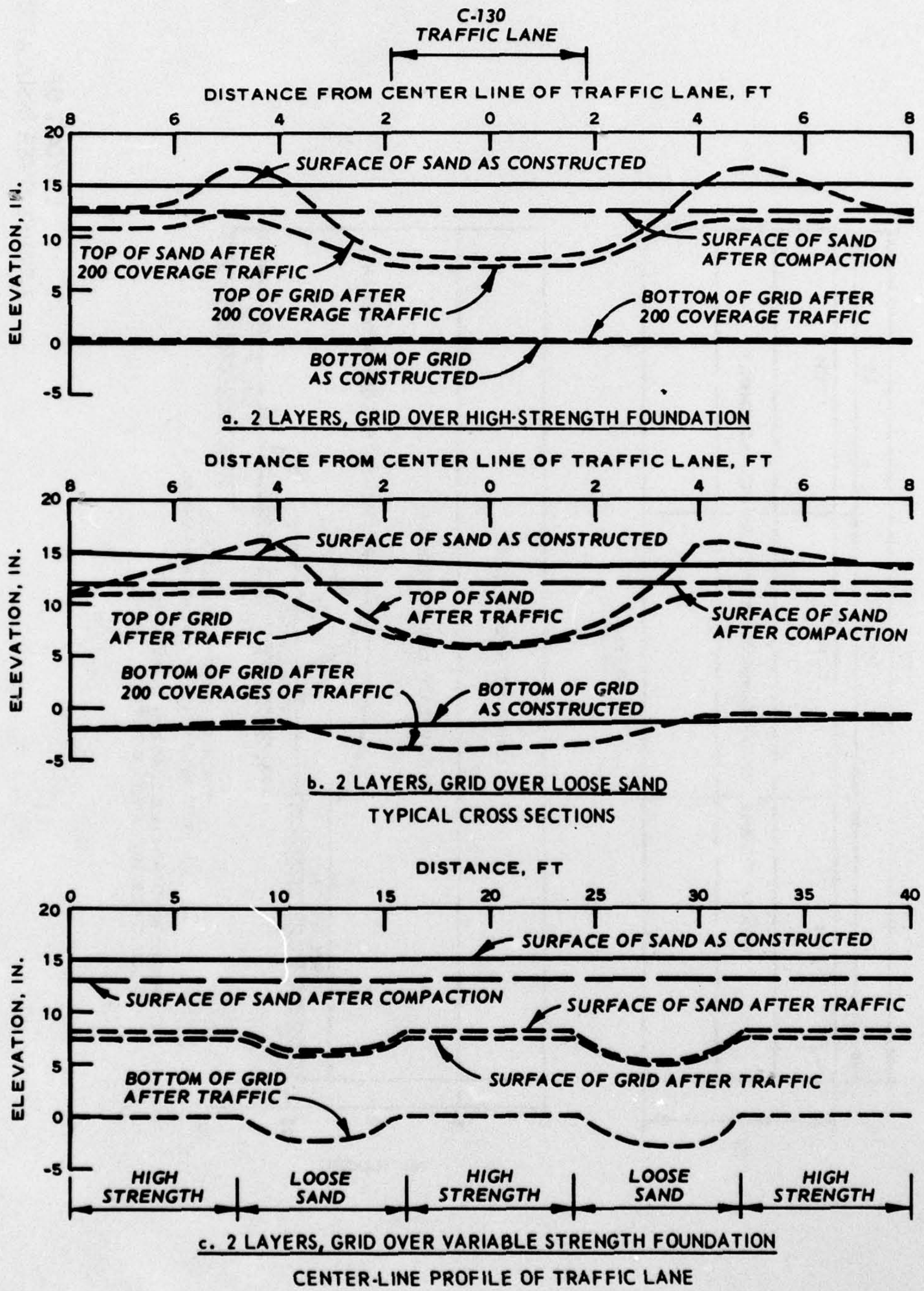
TEST SECTION NO. 3



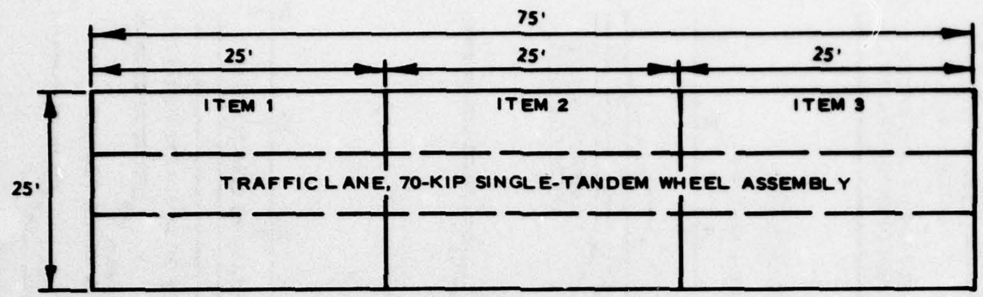
TYPICAL CROSS SECTIONS
TEST SECTION NO. 3

DEFORMATION AND COMPRESSION OF SAND GRID

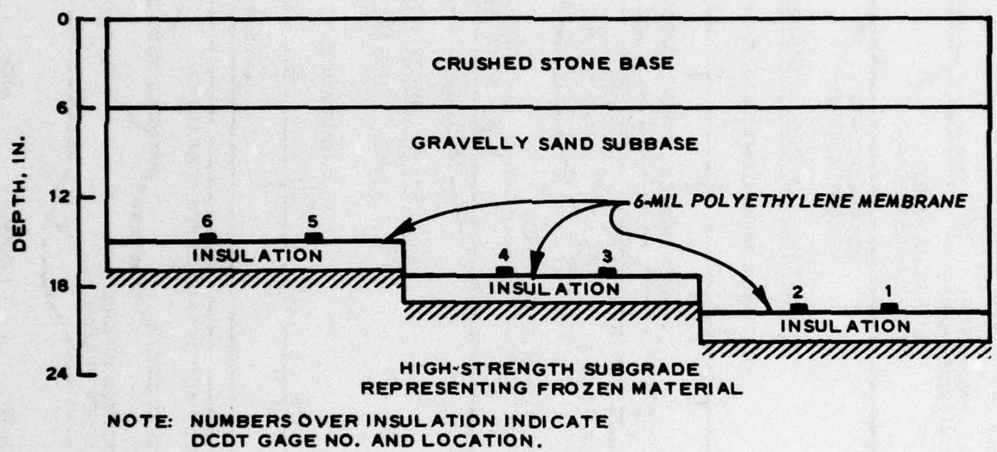
PLATE 10



CROSS SECTIONS AND PROFILE
TEST SECTION NO. 3, ITEM 4
DEFORMATION AND COMPRESSION
OF SAND GRID



PLAN

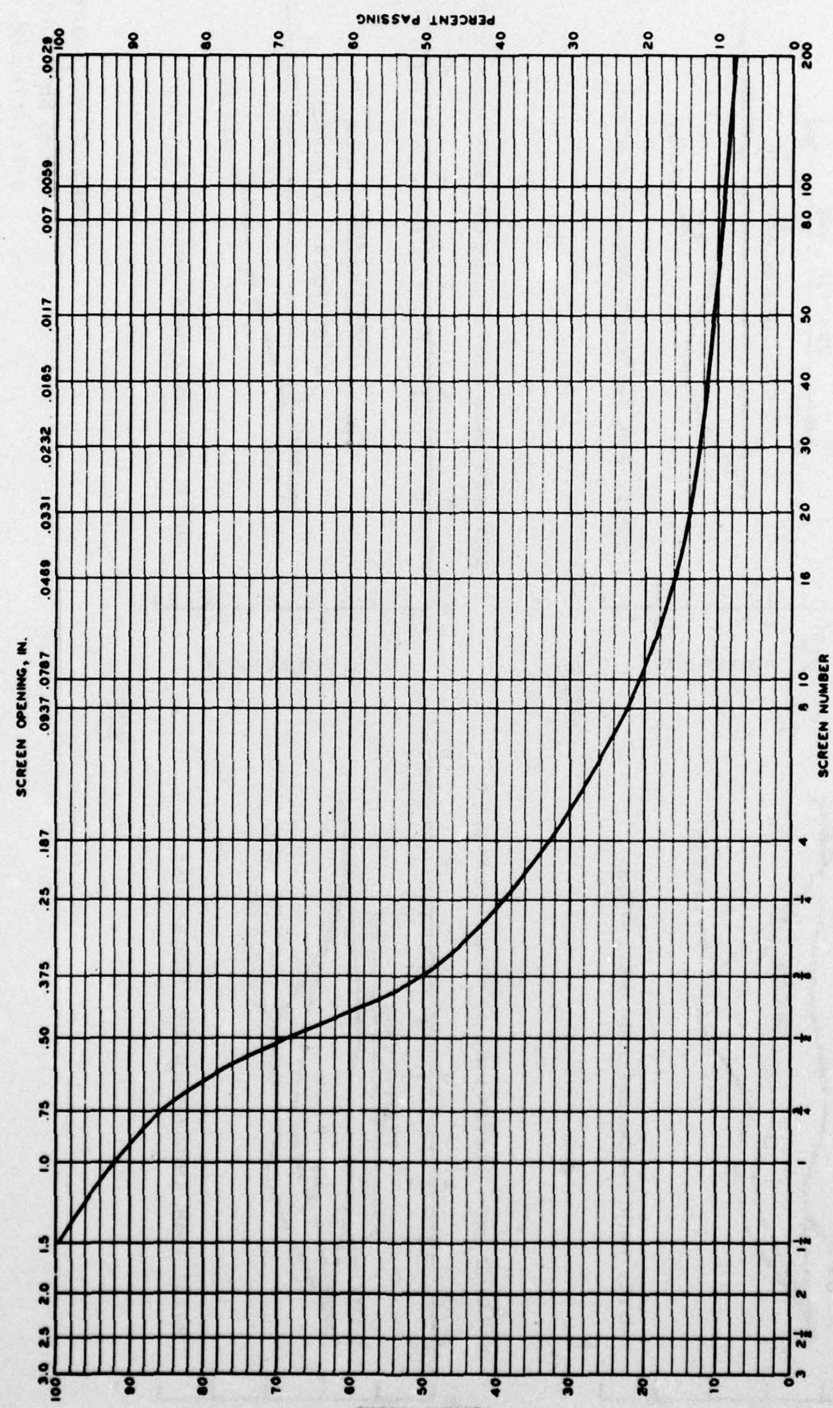


SECTION

LAYOUT OF
GRAVEL OVER INSULATION

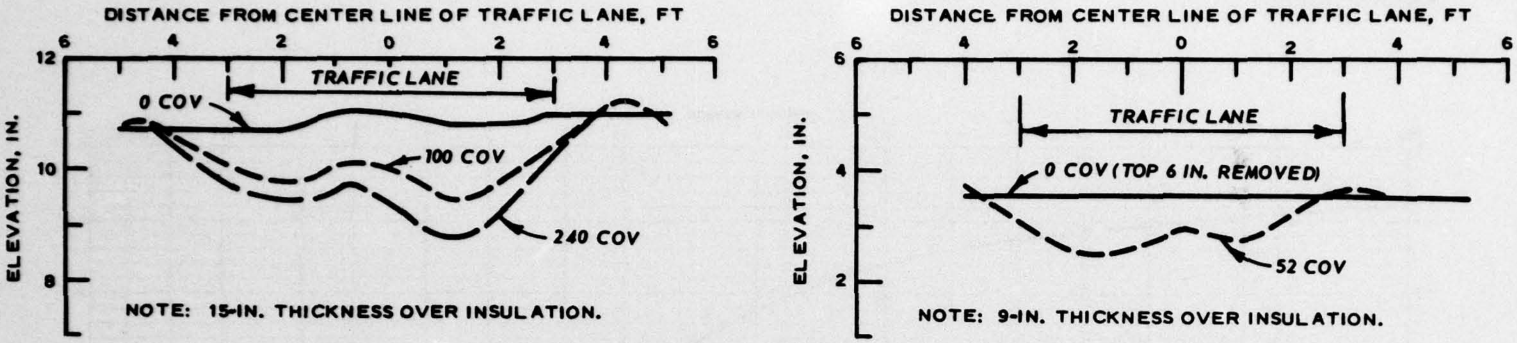
TEST SECTION NO. 4

PLATE 12

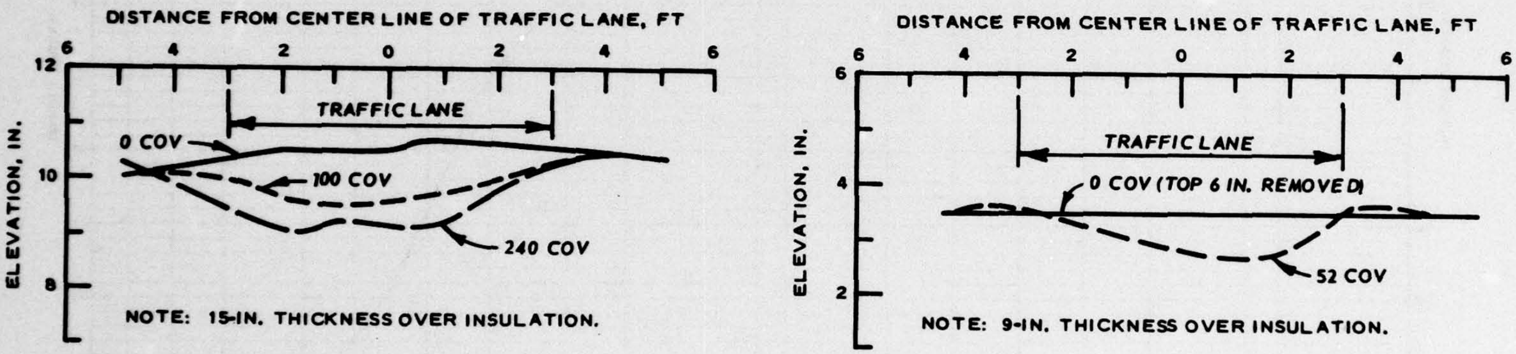


CRUSHED STONE
BASE COURSE MATERIAL

PLATE 13

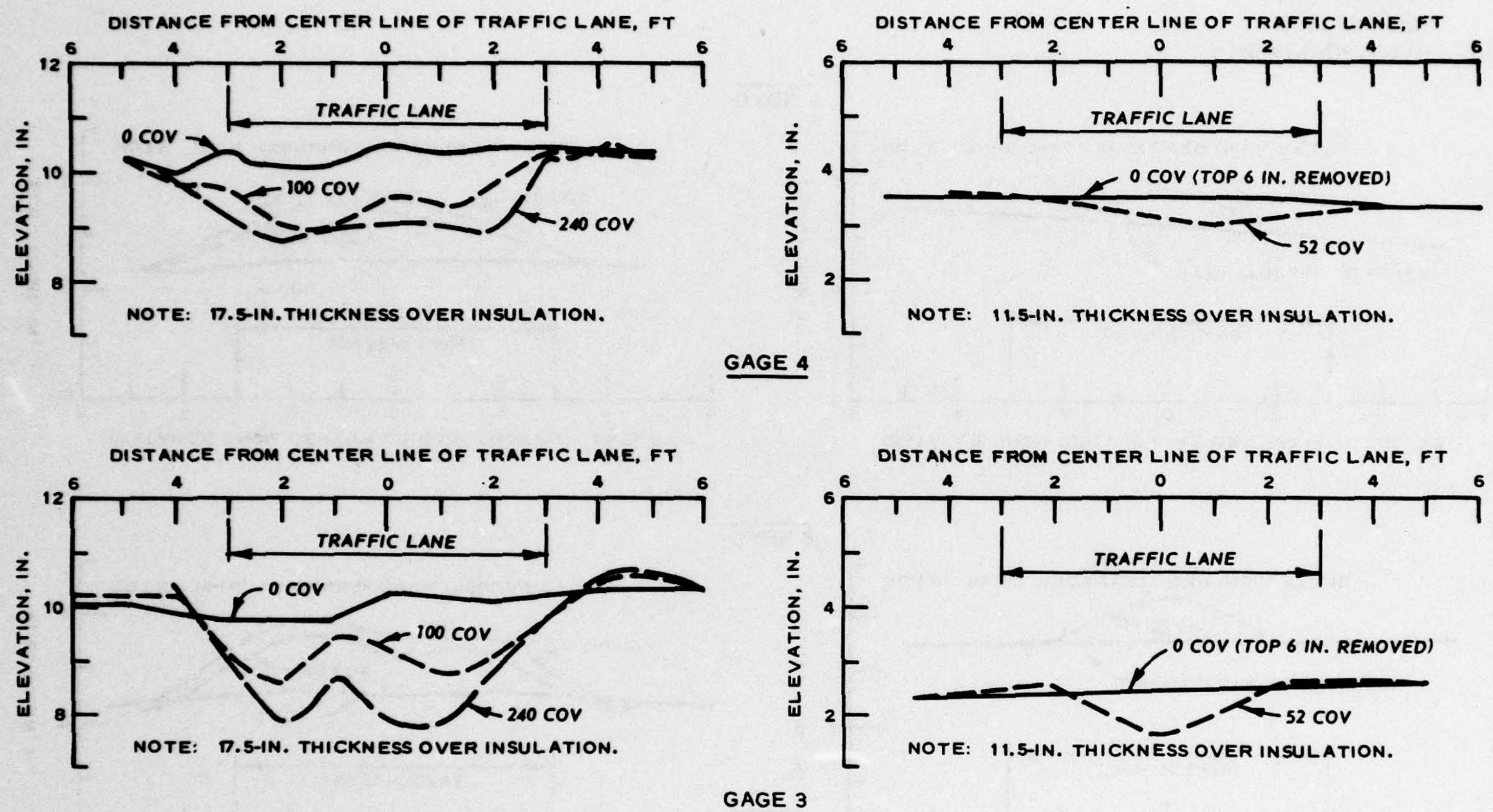


GAGE 6

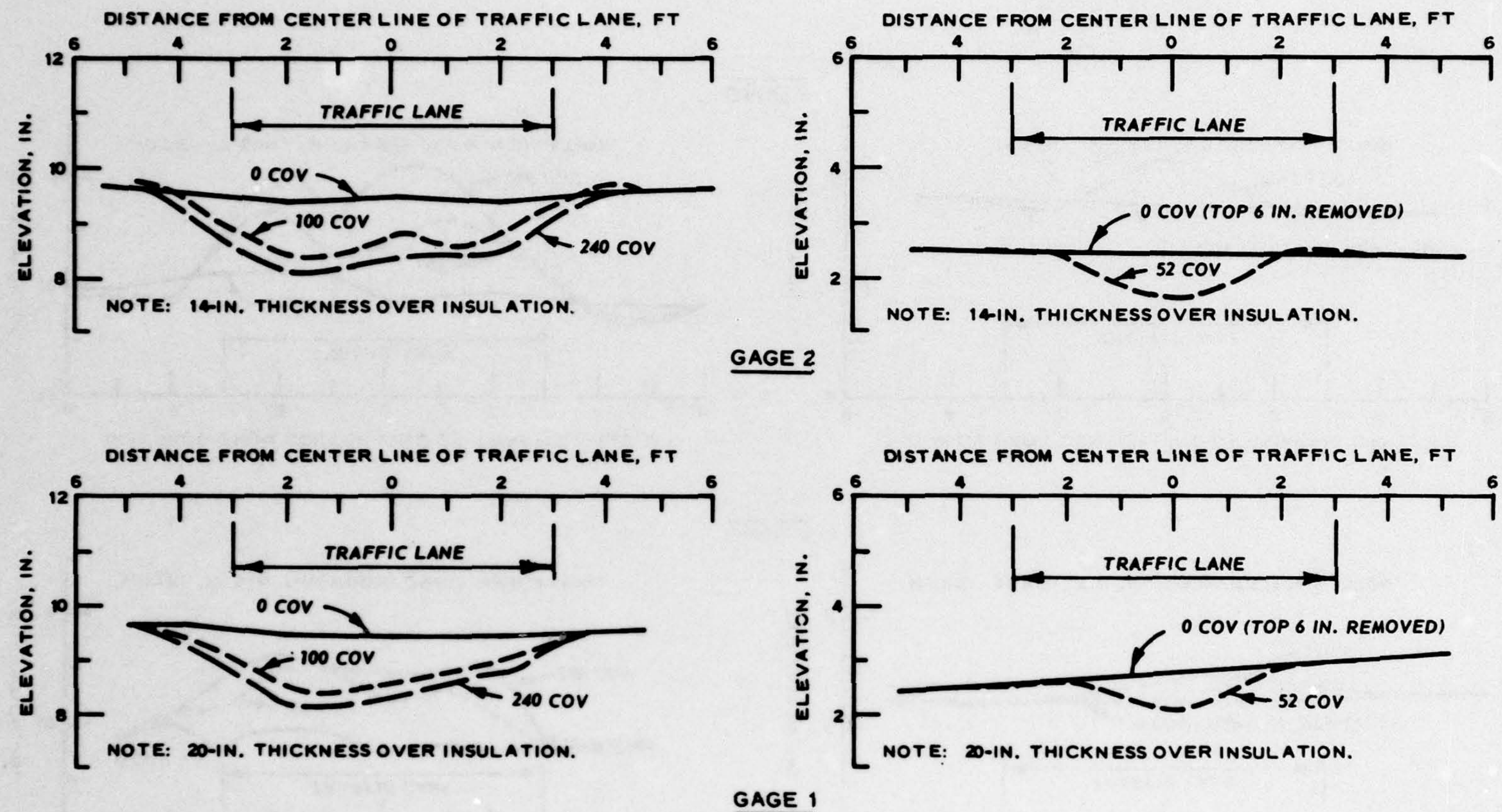


GAGE 5

SURFACE DEFORMATION
CROSS SECTIONS
TEST SECTION NO. 4
ITEM 1

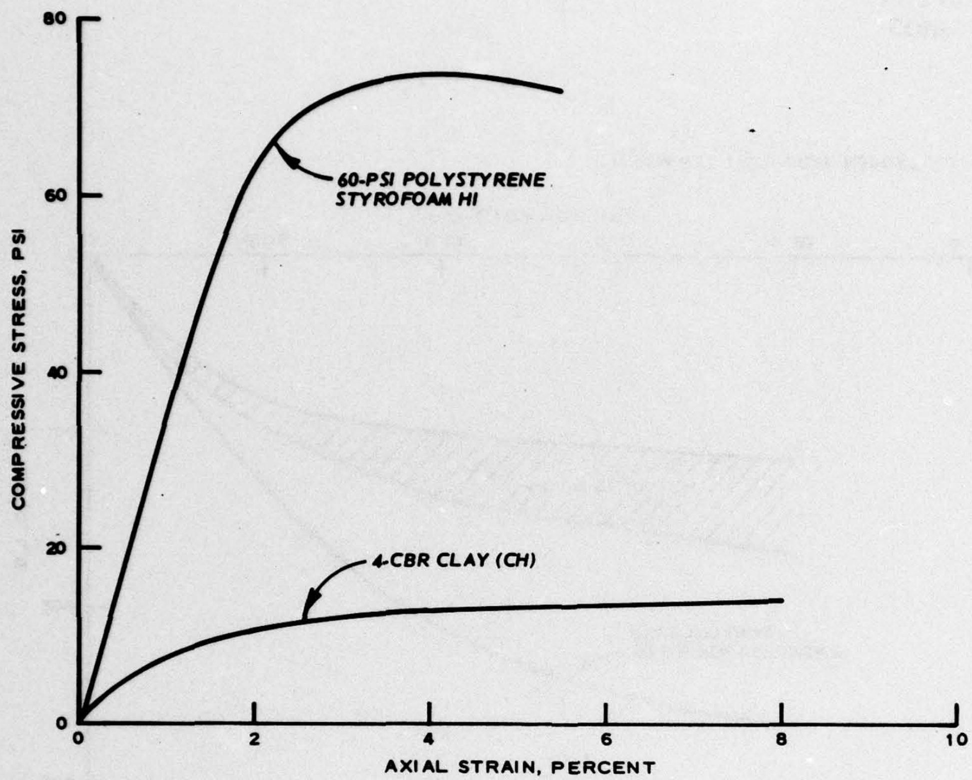


SURFACE DEFORMATION CROSS SECTIONS
TEST SECTION NO. 4, ITEM 2



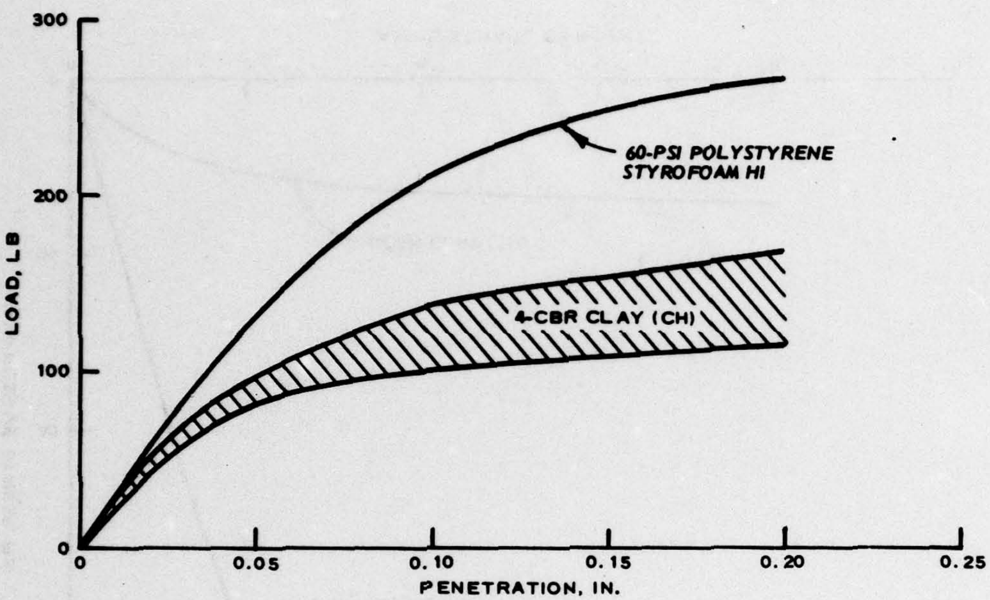
SURFACE DEFORMATION
CROSS SECTIONS
TEST SECTION NO. 4
ITEM 3

PLATE 16



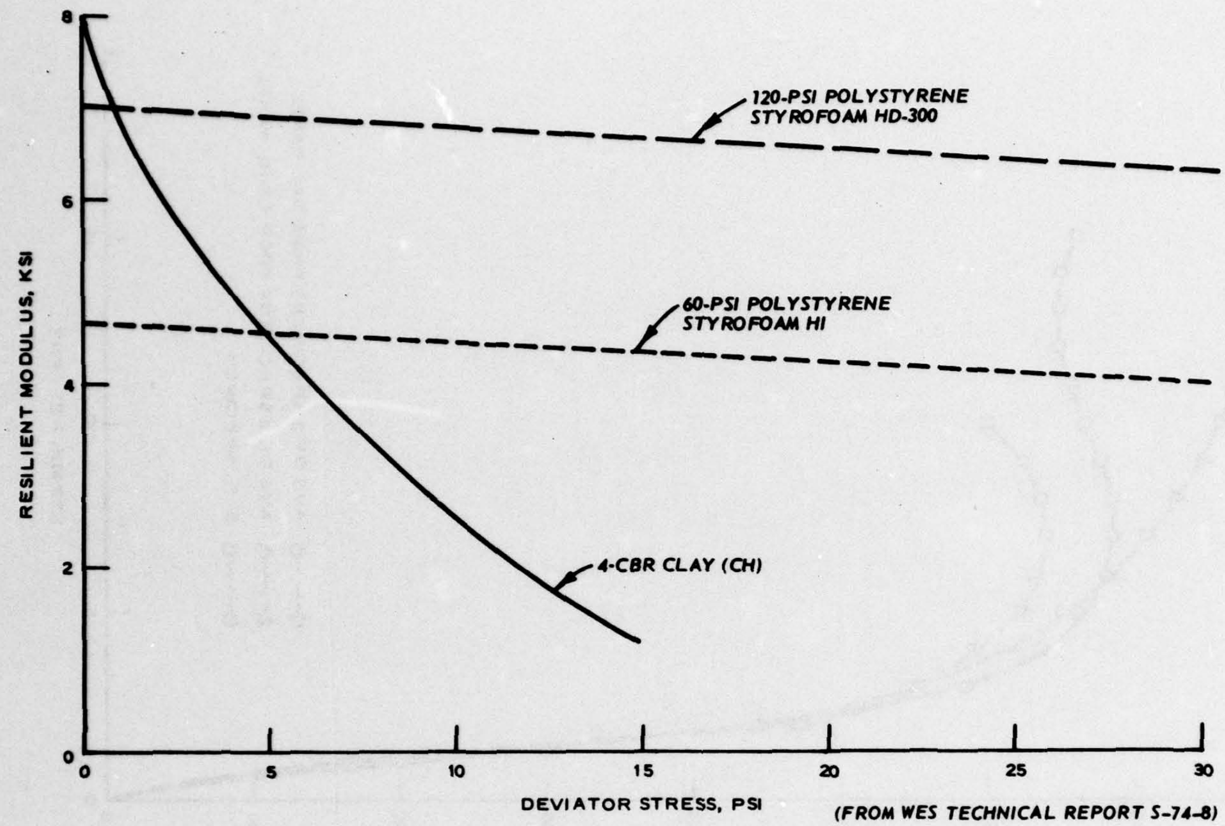
(FROM WES TECHNICAL REPORT S-74-8)

COMPARISON OF STRESS-STRAIN CURVE
FOR 60-PSI POLYSTYRENE AND
4-CBR CLAY (CH)



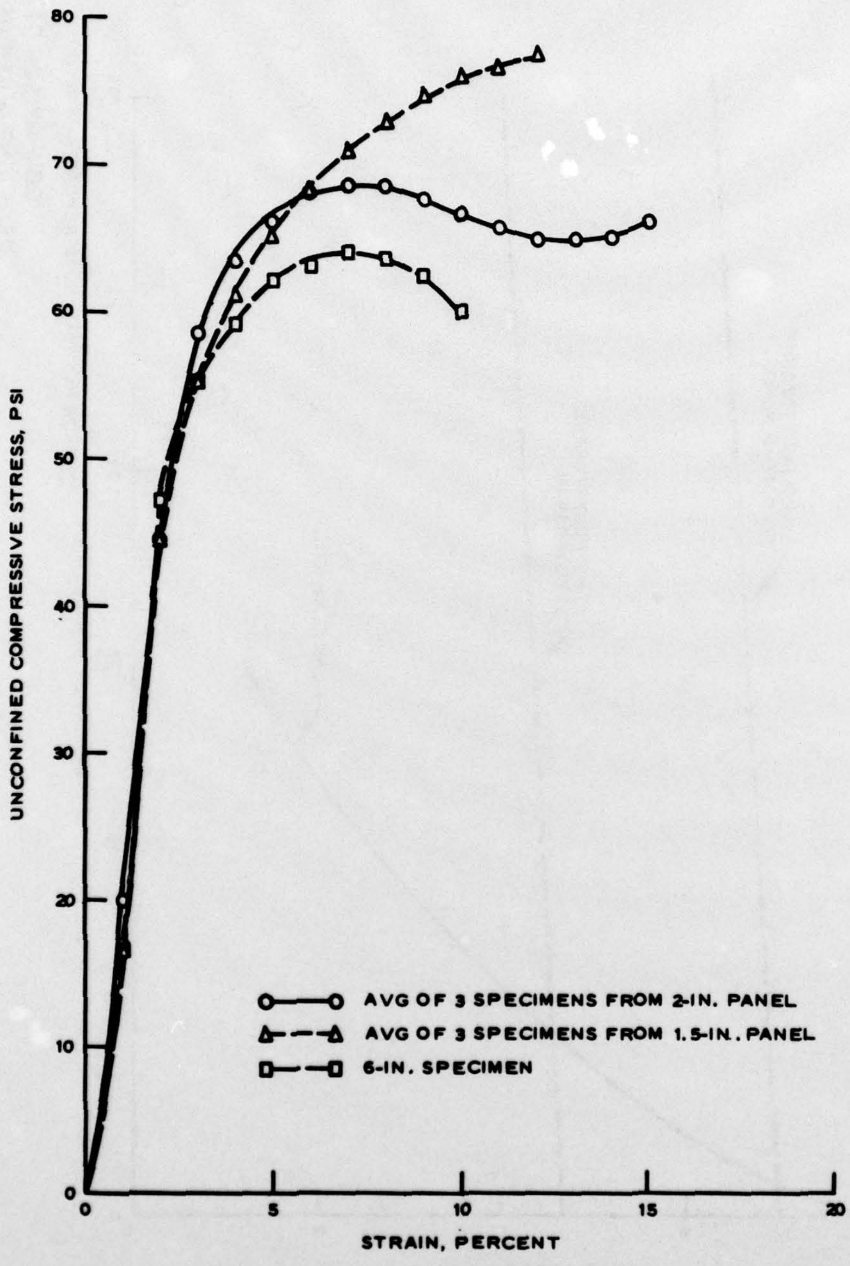
(FROM WES TECHNICAL REPORT S-74-8)

COMPARISON OF CBR CURVES
FOR 60-PSI POLYSTYRENE AND
4-CBR CLAY (CH)

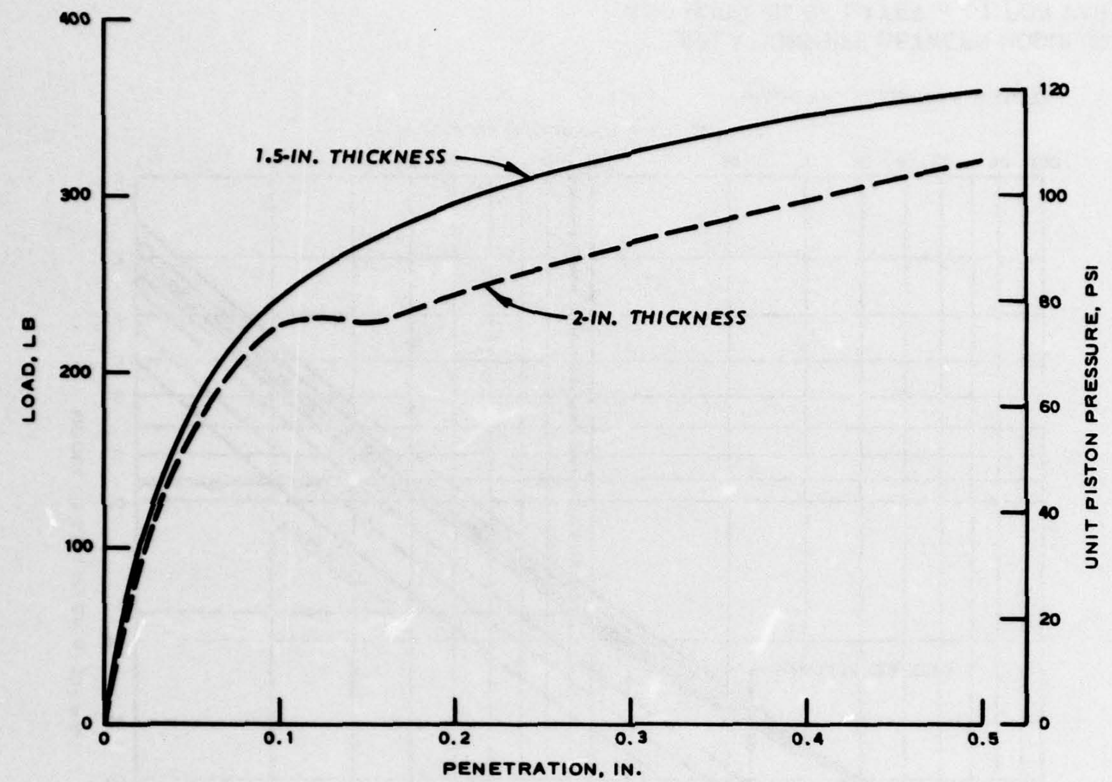


(FROM WES TECHNICAL REPORT S-74-8)

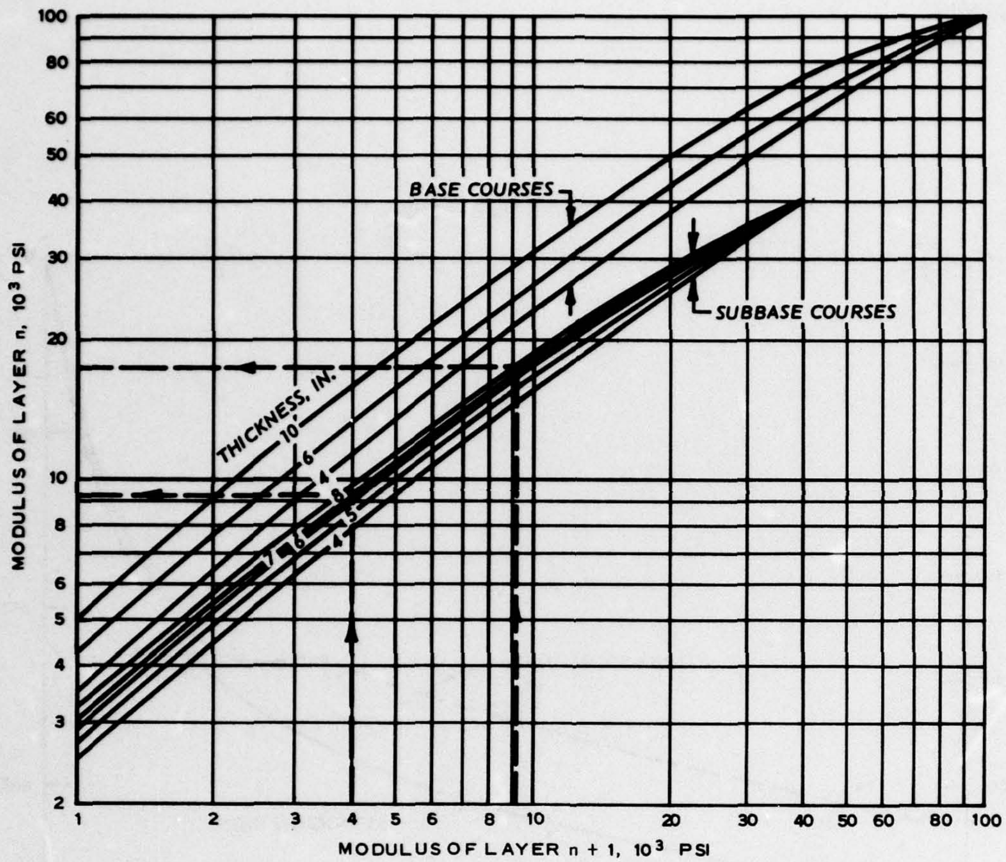
COMPARISON OF
RESILIENT MODULUS OF
120-PSI AND 60-PSI POLYSTYRENE
AND 4-CBR CLAY (CH)



RESULTS OF SINGLE-LOAD UNCONFINED COMPRESSION TESTS OF STYROFOAM HI MATERIAL

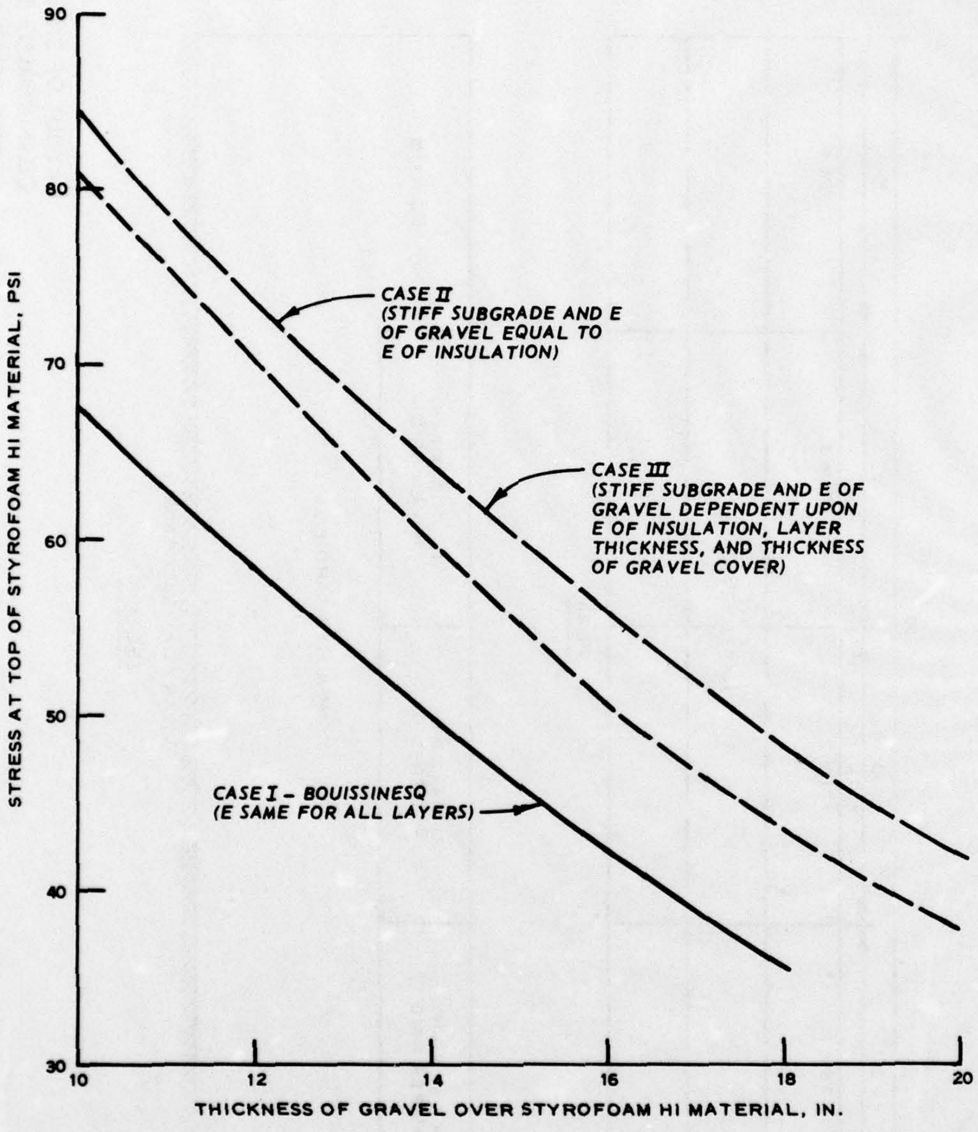


TYPICAL
CBR LOAD - PENETRATION
CURVES FOR STYROFOAM HI



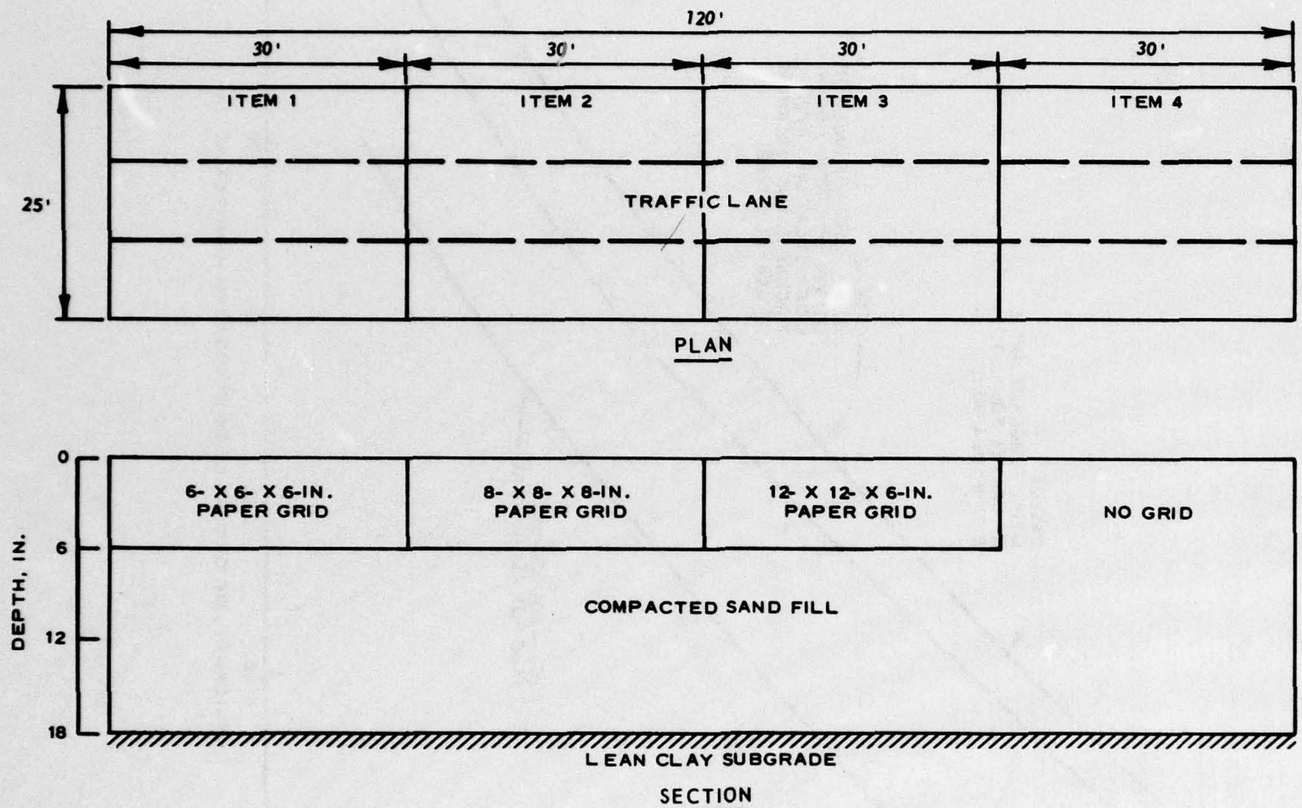
(FROM WES TECHNICAL S-75-17)

RELATIONSHIPS BETWEEN MODULUS OF LAYER n AND MODULUS OF LAYER n + 1 FOR VARIOUS THICKNESSES OF UNBOUND BASE COURSE AND SUBBASE COURSE



RELATIONSHIP BETWEEN
STRESS AT TOP OF INSULATION MATERIAL
AND THICKNESS OF GRAVEL COVER

PLATE 24



LAYOUT OF SAND-GRID
CONFINEMENT STUDY
TEST SECTION NO. 5

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Burns, Cecil Dawson

Traffic tests of expedient airfield construction concepts for possible application in the National Petroleum Reserve Alaska (NPRA) / by Cecil D. Burns. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

53, [56] p., 24 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; GL-79-2)

Prepared for Department of the Interior, U. S. Geological Survey, Menlo Park, California.

1. Airfield construction. 2. Construction in permafrost. 3. Expedient construction. 4. Expedient surfacings. 5. Insulation. 6. Landing mats. 7. National Petroleum Reserve Alaska. 8. Runways. 9. Traffic tests. I. United States. Geological Survey. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; GL-79-2.
TA7.W34 no.GL-79-2